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FIXED-ATTITUDE ABORT PROCEDURES FOR ABORTS OCCURRING DURING TRANSLUNAR INJECTION

By

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FIXED-ATTITUDE ABORT PROCEDURES FOR ABORTS OCCURRING DURING TRANSLUNAR INJECTION

FEBRUARY 15, 1968

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FOREWORD

This report presents the results of a fixed-attitude abort procedures study performed for the NASA Manned Spacecraft Center by TRW Systems, in accordance with Task MSC/TRW A-139, under Contract NAS 9-4810. Time critical earth horizon reference aborts, initiated as a result of a very severe onboard CSM failure during the translunar injection phase of a lunar landing mission, were examined to determine abort procedures and requirements to be used in the event that such a contingency should arise. Conclusions are presented for the fixed-attitude abort maneuver, a midcourse correction on the postabort trajectory, and postabort tracking coverage.

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NOMENCLATURE

AAWG	Apollo Abort Working Group
AGC	Apollo guidance computer
ARM04	Apollo Reference Mission Program, Version 4
CM	Command module
COAS	Command optical alignment system
CSM	Command service module
EMS	Entry monitor system
FDAI	Flight director attitude indicator
G&N	Guidance and navigation
KSC	Kennedy Space Center
L/D	Lift-to-drag ratio
MSC	Manned Spacecraft Center
MSFC	Marshall Space Flight Center
MSFN	Manned Spaceflight Network
RCS	Reaction control subsystem
RTCC	Real-time Computation Center
RTEAP	Return to earth abort processor
SCS	Stabilization and control subsystem
S-IVB	Third booster stage (Saturn V)
SM	Service module
SPS	Service propulsion subsystem
TERRA	Earth Abort Program
TLI	Translunar injection
UHF	Ultra-high frequency

T_{AR}	Time from abort to entry
T_B	S-IVB burn time
T_D	Delay time
T_{MR}	Time from midcourse correction to entry
V_{GO}	S-IVB velocity to be gained
γ_E	Flight-path angle
$\Delta\beta$	Pitch error
ΔV	Incremental change in velocity
ΔV_{MC}	Midcourse delta velocity
ψ	ΔV orientation angle

1. INTRODUCTION AND SUMMARY

1.1 PURPOSE

In recent meetings of the Apollo Abort Working Group (AAWG), the question of how to safely return the flight crew to earth in the event of a catastrophic command service module (CSM) failure during the translunar injection (TLI) burn was discussed. While the existence of such severe contingency situations is questioned at the present time, the area does require investigation in the event that a catastrophic failure of this type is defined at a future time. It is emphasized that the abort procedure developed herein is a time-critical, survival type mode with the sole purpose of returning the flight crew to earth as quickly as possible within the entry corridor, but without regard to landing conditions. Therefore, this abort procedure must be as straightforward as possible and be independent of ground support. The purpose of this report is to present the results of a study to determine the feasibility of performing a fixed-attitude abort maneuver, using the earth's horizon as a reference, at a fixed time after a manual shutdown of the TLI burn.

1.2 SCOPE

The feasibility of the fixed-attitude abort procedure was investigated for two launch dates and three launch azimuths applicable to the lunar landing mission. No anomalies in these TLI trajectories were considered since it is assumed that a spacecraft failure rather than a launch vehicle failure has caused the abort. Consideration has been given to the effects of possible attitude errors associated with the fixed-attitude abort maneuver, and midcourse maneuver requirements have been investigated. Preliminary crew charts are presented as are both preabort and postabort tracking information. Ground traces and landing location data are also provided.

Only inplane, impulsive maneuvers have been considered to establish the feasibility of the fixed-attitude abort procedure. A preliminary study using a finite burn maneuver has just recently been published (Reference 1).

1.3 SUMMARY

The results of this study indicate that it is operationally feasible to perform a time-critical abort maneuver after manually aligning the spacecraft to a fixed attitude with respect to the earth's horizon, and delaying SPS ignition a fixed time after terminating the TLI burn. The ΔV required for the abort maneuver, which is targeted for the center of the entry corridor, would be available to the flight crew from onboard charts. In all cases the ΔV required is less than 5,000 feet per second. Return flight times are less than 6 hours in duration. The sensitivity of the abort maneuver to attitude errors associated with the manual attitude alignment and SPS pointing errors in the stabilization and control subsystem (SCS) ΔV mode require that midcourse maneuvers be performed for aborts occurring late in the TLI burn. The midcourse correction is a minimum fuel unspecified area maneuver that is targeted to the center of the entry corridor. This maneuver can be computed by the flight crew using the onboard programs. A fixed-attitude scheme similar to that specified for the abort maneuver was originally considered, but was abandoned because of the purported difficulty in manually aligning the spacecraft in the orbit plane at the high altitudes where a midcourse correction would be performed.

The procedure thus defined has been designed for implementation by the flight crew with the aid of crew charts and onboard programs. Although ground support is not mandatory, adequate tracking coverage exists for the mission studied to allow ground support of the fixed-attitude abort maneuver and, if required, the midcourse maneuver. In those situations where communication with the ground is not possible, the procedure is still applicable providing the Apollo guidance computer (AGC) is operative.

There is a high percentage of land landings and night landings or both; however, this abort procedure would not be used except in the case of a catastrophic spacecraft failure where the lives of the flight crew were already in extreme danger.

2. THE FIXED-ATTITUDE ABORT MANEUVER

2.1 GENERAL

The discussion in this section centers on the fixed-attitude abort maneuver from both a trajectory and an operational viewpoint. Included is a discussion of the TLI burn simulations, the abort maneuvers, the use of crew charts, postabort groundtracks, and landing point traces. At this point it should again be emphasized that the horizon reference abort described in this study is a manual abort which can be executed independently of ground support, and is used only in the event of one of a limited type of very severe CSM failures which require immediate S-IVB shutdown and separation of the CSM and S-IVB. For a discussion of these failures, see Reference 2. Other types of failures may occur during TLI which do not necessarily require S-IVB shutdown and which may lead to the adoption of an alternate mission.

2.2 TLI BURN SIMULATIONS FOR THE LUNAR LANDING MISSION

In order to investigate the feasibility of the fixed-attitude abort maneuver, six TLI burn simulations were made, all associated with the early AS-504 lunar landing mission. In order to cover a wide range of possible launch conditions, two launch dates, 1 February and 4 February 1968, were selected; and for each date launch azimuths of 72, 90, and 108 degrees were chosen. The 72- and 108-degree launch azimuths represent the maximum northerly and southerly launch limits attainable from KSC due to range safety considerations and cover a greater span than the 26-degree total range permitted by insertion ship tracking requirements. Six TLI burn simulations for the launch dates and launch azimuths cited above were supplied by the Flight Analysis Branch of MSC. The ARM04 program was used to generate the trajectories, using mixture ratios and target parameters supplied by MSFC. State vectors were generated at constant intervals of S-IVB burn time, T_B, throughout the major portion of each burn. A typical TLI burn profile of S-IVB velocity to be gained, V_{GO}, versus T_B is shown in Figure 2-1.

2.3 THE ABORT MANEUVER

In defining the fixed-attitude abort procedures the following guidelines were established:

- In the interests of crew safety, a simple, readily performed procedure was adopted, with an attempt to fix as many of the abort parameters as possible.
- In view of the conditions under which this procedure will be executed, a near time-critical return to earth was selected.
- If time permits during the return flight, a midcourse correction may be made to ensure an entry which is targeted to the corridor centerline.
- No consideration was given to the landing area or local time of landing. It is thus possible for the CM to make a land landing in darkness.

The basic geometry of the horizon reference type of abort is shown in Figure 2-2. The maneuver is nominally coplanar. Heads up and heads down attitudes can be defined by examining the figure. In the heads up attitude the CSM +X-axis (essentially in the direction of the applied $\Delta\overline{V}$) is located below (toward the center of the earth) the line of sight to the horizon, while in the heads down attitude the +X-axis is aligned above the line of sight to the horizon. The ΔV orientation angle, Ψ, is measured positive for clockwise rotations.

In the event of an onboard failure during the TLI burn which calls for the fixed-attitude type of abort, the crew has several steps to follow prior to the abort maneuver (Reference 3). Upon recognition and confirmation of such a failure, the S-IVB is shut down immediately by the crew and separation of the CSM from the S-IVB stage is begun by applying RCS thrust along the +X-axis of the CSM. After separation has been achieved, the ΔV monitor (entry monitor system , EMS) is set to the correct value determined from crew charts with the knowledge of V_{GO} (or some suitable parameter) at the time of the S-IVB shutdown, and the crew prepares for a SCS ΔV auto abort. The command pilot adjusts his position in the couch to the docking position which is required for the manual execution of the abort maneuver. If communications and RTCC response time permit, telemetry from the ground may furnish IMU gimbal angles and verify the

ΔV in the counter. However, the success of the maneuver is not dependent upon ground support. The crew manually aligns the CSM at an angle of +5 degrees with respect to the far horizon using a reticule mounted on the command pilot's window (command optical alignment system, COAS) as a visual aid and performs the alignment of the Flight Director Attitude Indicator (FDAI). This attitude is held until precisely 10 minutes after S-IVB shutdown when the SPS is ignited in the SCS ΔV auto mode. The actual times associated with these events are shown in Table 2-1 as defined in the minutes of the nineteenth Apollo Abort Working Group (Reference 3). A study of the CSM/S-IVB separation sequence is being conducted in order to establish a more refined timeline for this phase of the abort procedure.

The value of ψ, the angle between the CSM +X-axis and the line of sight to the reference horizon, and the value of T_D, the delay time or time interval between S-IVB shutdown and SPS ignition, have been fixed at +5 degrees and 10 minutes, respectively (Reference 4). Previous studies (Reference 5) have shown that the type of abort using the near horizon as a reference does not satisfy the requirements of the present study. Aborts performed in a heads down attitude to the far horizon have return flight times which are too long in view of the time-critical situation resulting from a catastrophic onboard failure. Only aborts performed in a heads up attitude to the far horizon have both acceptable entry velocities and return flight times. Thus, the fixed-attitude aborts discussed in this study are made in a heads up attitude to the far horizon. As seen in Reference 4, the role of the attitude alignment error is quite important and is a major consideration in the choice of ψ, along with the return flight time. The delay time, however, in the interval $10 \leq T_D \leq 30$ minutes, does not exhibit the same influence on alignment error sensitivities as the horizon reference angle. The selected T_D value of 10 minutes is based primarily on the return flight time.

With values of T_D and ψ defined and the far horizon selected as the attitude reference, abort trajectories were calculated using the TERRA program for various state vectors along each of the TLI burn simulations discussed in Section 2.2. Each of the state vectors chosen represents a possible time of manual S-IVB shutdown due to a CSM failure of the type described in Section 2.1. The state vectors were propagated by numerical integration for a time of 10 minutes, and the abort maneuver was then simulated by an impulsive burn directed at an angle of Ψ = +5 degrees with respect to the far horizon. A maximum SPS ΔV of 10,000 feet per second is available for the burn. The resulting postabort trajectories were approximated by two body conics to the entry altitude. Starting at the entry altitude, a curve fitting technique was employed to obtain the landing point, using a CM lift-to-drag ratio (L/D) of 0.33.

The entry corridor used for this study is shown in Figure 2-3. Definition of the corridor is established by the 10g full-lift undershoot limit line and the zero-lift overshoot limit as cited in Reference 6. The entry corridor centerline is defined by a simple average of the flight-path angle, γ_E, for each of the two boundaries at constant values of inertial entry velocity. All postabort trajectories were targeted to this centerline.

Figures 2-4 to 2-7 illustrate the ΔV required for the abort maneuver and the postabort flight time. In Figures 2-4 and 2-5, the abort ΔV is shown as a function of both V_{GO} (S-IVB velocity to be gained) and T_B (S-IVB burn time) for both launch days and all launch azimuths considered. A change in the launch azimuth has little effect on the abort ΔV. Although both V_{GO} and T_B are displayed to the crew during the TLI burn, V_{GO} provides a more direct evaluation of S-IVB engine performance and for this reason is preferred to T_B. For all cases the required ΔV is well below the maximum available SPS capability of 10,000 feet per second. The continuous increase of ΔV, as V_{GO} decreases, arises from the increasing energy of the preabort trajectories as the S-IVB burn continues. Figures 2-6 and 2-7 present the time from abort to entry, T_{AR}, as a function of both V_{GO} and T_B. Again, T_{AR} is only slightly affected by a change in the launch azimuth. The return flight times exhibit a continuous increase as the TLI phase progresses, with a maximum flight time of less than 6 hours.

2.4 CREW CHARTS

In order for the crew to successfully initiate the abort maneuver, a value for the ΔV required must be supplied independently of the ground, since the time interval between S-IVB shutdown and SPS ignition is only 10 minutes. Such information could be provided by a crew chart showing the abort ΔV as a function of the S-IVB V_{GO} at shutdown for the launch date and launch azimuth, together with the time to fire, T_D, and the horizon reference angle, Ψ. Examples of this information are presented in Figures 2-4 and 2-5. Knowing the value of S-IVB V_{GO} at shutdown, the corresponding value of ΔV may be read from the appropriate figure.

During the nineteenth AAWG meeting, it was suggested that a mean curve might be used for all launch azimuths on a given launch date, and possibly for all launch dates, thus reducing the number of necessary charts. To test the possibility of this technique, a Lagrange interpolation routine was developed to find the ΔV for specified values of V_{GO} from an input table of V_{GO} and ΔV values. This step was necessary since the ARM04 data were incremented according to the burn time instead of V_{GO} and thus prohibited a direct comparison of ΔV values for the various launch azimuths having the same value of V_{GO}. By using the interpolation routine a mean curve for each launch date was constructed by averaging the ΔV values for launch azimuths of 72 and 108 degrees at constant values of V_{GO}. The mean curves for 1 February and 4 February are shown in Figures 2-8 and 2-9, respectively. These are presented on a full grid to illustrate the resolution available on a typical crew chart. In the region of high V_{GO} values (9000 feet per second) the mean represents a deviation of about 10 feet per second from either the 72- or 108-degree launch azimuth data, while in the region of low V_{GO} values (1000 feet per second) the dispersions are typically 75 feet per second.

The sensitivity of the postabort trajectory to ΔV dispersions of the magnitude indicated above was examined next, again using the TERRA program. Several state vectors from the 4 February, 72-degree launch azimuth TLI simulation were propagated 10 minutes to the abort maneuver point. At this point the program did not internally calculate the value of ΔV to be used for the abort maneuver (i. e., that required to hit the corridor centerline) but instead used the value of ΔV found from a crew chart at the appropriate V_{GO} value. The value of ΔV actually employed was taken from the plot of ΔV versus V_{GO} for the 4 February, 90-degree launch azimuth TLI simulation (Figure 2-4). This is a conservative approach, since the 90-degree plot yields slightly larger deviations in ΔV

than the mean ΔV versus V_{GO} plot for 4 February. Dispersions introduced in the value of ΔV used for the abort maneuver vary between 10 feet per second ($V_{GO} \simeq 9000$ feet per second) and 90 feet per second ($V_{GO} \simeq$ 1000 feet per second). An error due to reading the ΔV value off the graph is also introduced, which amounts to about 20 feet per second. Results of this study are summarized in Table 2-2. A previous study (Reference 7) has shown that ΔV errors of the order of 100 feet per second or less can be completely ignored with undetectable dispersions at entry. For the larger ΔV dispersions encountered in this analysis the largest deviation in flight-path angle at entry is observed to be less than 0.25 degree from the corridor centerline. Even though this occurs at the highest entry velocity, a safe entry is still achieved.

2.5 DISCUSSION OF POSTABORT GROUNDTRACKS AND LANDING POINT TRACES

The final topic to be covered in this section is a discussion of the postabort groundtracks and the landing or touchdown points of the CM following a nominal abort maneuver with the postabort trajectory targeted to the entry corridor centerline. As mentioned previously, the place and local time of landing are not constrained, since this abort procedure is used only in the event of a catastrophic CSM failure. In fact, the results demonstrate that touchdowns on land or in darkness are fairly common.

Postabort groundtracks for several S-IVB shutdown times are shown in Figures 2-10 to 2-15 for 1 February 1968, with a launch azimuth of 72 degrees. Since the groundtracks pass through the southern part of the United States it may be anticipated that tracking coverage will be very good, particularly for the first part of the abort trajectory. Section 4 will discuss this aspect of the study in considerable detail. It is seen for the later burn times that the groundtracks become rather asymmetrical as the S-IVB burn time increases, and become almost vertical at a longitude of 68° W for the nominal TLI burn. This results from the near equality of the CSM orbital velocity and the earth's rotational velocity at the sub-CSM point.

Groundtracks for the other launch azimuths on 1 February and all three launch azimuths for 4 February are shown in Figures 2-16 to 2-21 for three representative burn times.

A trace of the landing points for the complete range of burn times (or values of V_{GO}) is presented for each of the six TLI simulations used in this study in Figures 2-22 and 2-23. For both launch dates a launch azimuth of 72 degrees exhibits fewer land touchdowns than the other trajectories. A westward shift in the landing traces is seen for each launch date as the launch azimuths become more southerly. The frequency of water to land touchdowns for each TLI simulation is shown in Figures 2-24 and 2-25 for the range of V_{GO} during TLI. In addition, the frequency of land touchdowns for all launch azimuths combined on each launch date is displayed. Except for the two cases mentioned above, land touchdowns occur rather frequently. Figures 2-24 and 2-25 also indicate the lighting conditions at touchdown. Nearly all landings for 1 February occur in darkness while for 4 February those in daylight predominate.

This may be explained in terms of the different launch times for the same launch azimuth on the two days considered, and the fact that the postabort velocity of the CSM relative to the earth decreases as the S-IVB burn time increases. The later launch time on 4 February plus the earth-sun geometry causes the trace of landing points to transverse the earth's dark side fairly quickly, since the terminator is first crossed early in the burn ($T_B \sim 48$ seconds), when the CSM velocity relative to the earth (or the terminator) is fairly high. On 1 February, however, the launch time is approximately four hours earlier and as a result the landing point trace first crosses the terminator at a time point later in the burn ($T_B \sim 68$ seconds) with a lower CSM velocity relative to the terminator. This velocity difference is sufficient to insure that the remainder of the landing point trace for 1 February lies in darkness.

2.6 SUMMARY

Based on the analysis performed in this section, the following conclusions are drawn:

- A simple, readily performed procedure can be adopted for the fixed-attitude (heads up) type of abort, with the horizon reference angle and the time of abort fixed at +5 degrees with respect to the far horizon and 10 minutes after S-IVB shutdown, respectively.

- For all launch dates and azimuths considered, less than half of the available SPS ΔV is required by the abort maneuver.

- The return flight times for the launch dates and azimuths considered are all less than six hours.

- It appears feasible to use a single crew chart (i. e., a plot of ΔV as a function of V_{GO}) for each launch date, irregardless of the launch azimuth, in order to obtain the abort ΔV. In fact, the difference between the two daily crew charts is so small ($\lesssim$ 20 feet per second) that it is entirely practical to use either one as a crew chart for all launch dates and azimuths.

- The landing point traces show relatively few land touchdowns (< 10 percent) for the two launch dates having launch azimuths of 72 degrees. For all other launch azimuths, the frequency of land touchdowns is much higher, between 20 and 58 percent.

- Landings in darkness occur approximately 85 percent of the time for the possible landing points on 1 February for all launch azimuths considered. On 4 February the percentage of landings in darkness decreases by more than a factor of two, to 38 percent, again for all launch azimuths considered.

Table 2-1. Sequence of Events Timeline for the Fixed-attitude Abort

Time (min:sec)	Event
00:00	Terminate S-IVB thrust, RCS +X-axis on
00:03	CM/S-IVB separation
01:30	Separation completed, RCS +X-axis off
04:00	ΔV monitor set to correct value from crew charts, prepare for SCS ΔV auto
05:00	Command pilot in position, ground send IMU gimbal angles and verify ΔV in counter if possible
09:30	FDAI align
10:00	SPS ignition

Table 2-2. Entry Corridor Analysis Using an External Abort ΔV Input (Launch Date: 4 February 1968, Launch Azimuth: 72 Degrees)

S-IVB Burn Time, T_B(sec)	Abort Delta Velocity, ΔV(fps)	Entry Velocity, V_E(fps)	Entry Flight-path Angle γ_E(deg)	Crew Chart (Launch Azimuth = 90 deg) Input ΔV(fps)	V_E'(fps)	γ_E'(deg)	$\delta V_E = V_E' - V_E$ (fps)	$\delta\gamma_E = \gamma_E' - \gamma_E$ (deg)
30	1,405	25,180	-3.04	1,415	25,170	-3.03	-10	-0.01
60	1,687	25,610	-3.47	1,665	25,590	-3.51	-20	0.04
90	1,928	26,180	-3.94	1,900	26,150	-4.00	-30	0.06
120	2,126	26,830	-4.31	2,085	26,800	-4.40	-30	0.09
160	2,364	27,820	-4.66	2,295	27,770	-4.83	-50	0.17
200	2,619	28,890	-4.94	2,535	28,820	-5.15	-70	0.21
240	2,951	29,990	-5.25	2,880	29,930	-5.42	-60	0.17
280	3,420	31,150	-5.43	3,330	31,080	-5.65	-70	0.22
300	3,738	31,720	-5.54	3,645	31,640	-5.75	-80	0.21
333.66	4,450	32,660	-5.68	4,350	32,590	-5.91	-70	0.23

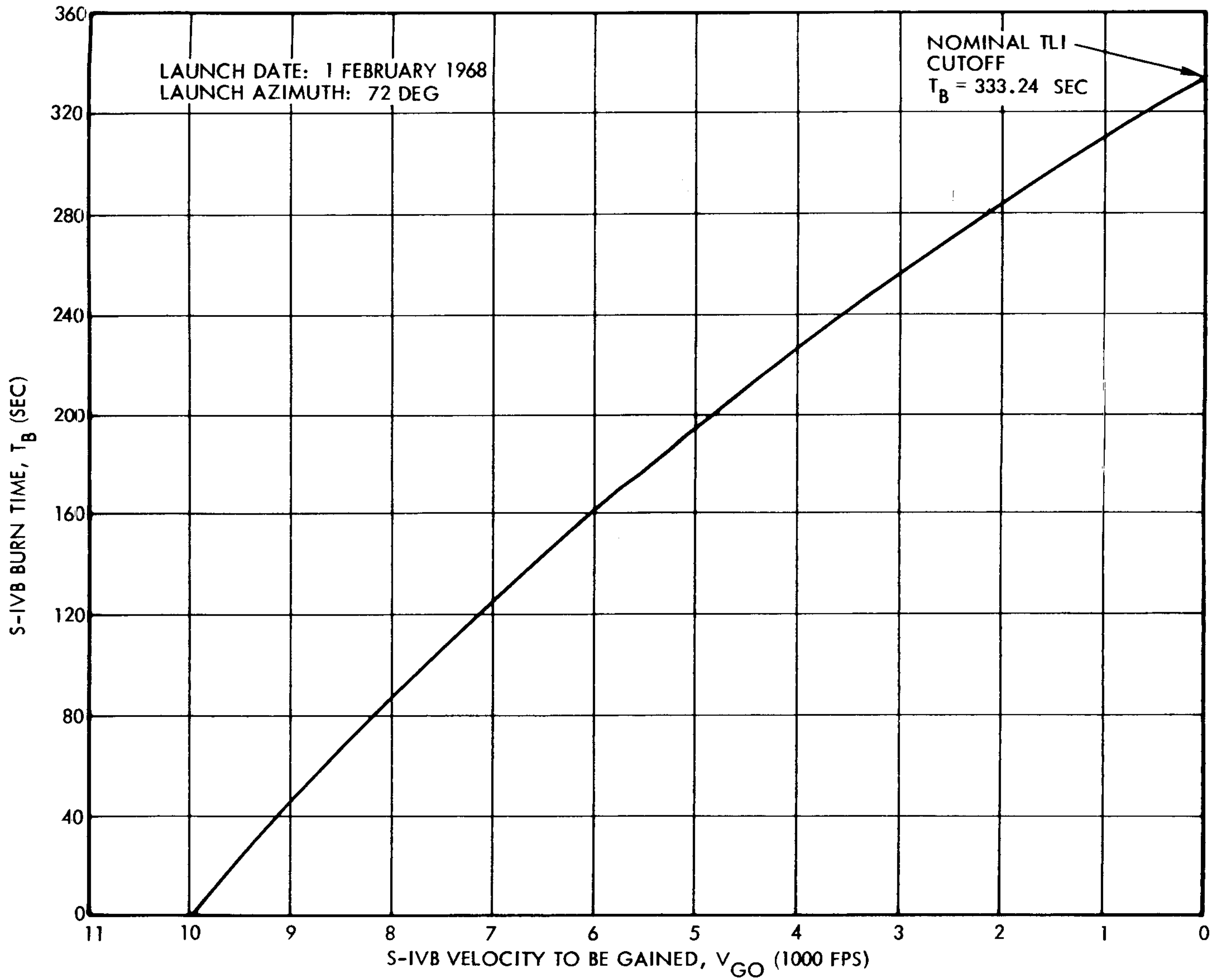

Figure 2-1. A Typical S-IVB Burn Profile Showing S-IVB Velocity to be Gained as a Function of S-IVB Burn Time for 1 February; Launch Azimuth of 72 Degrees

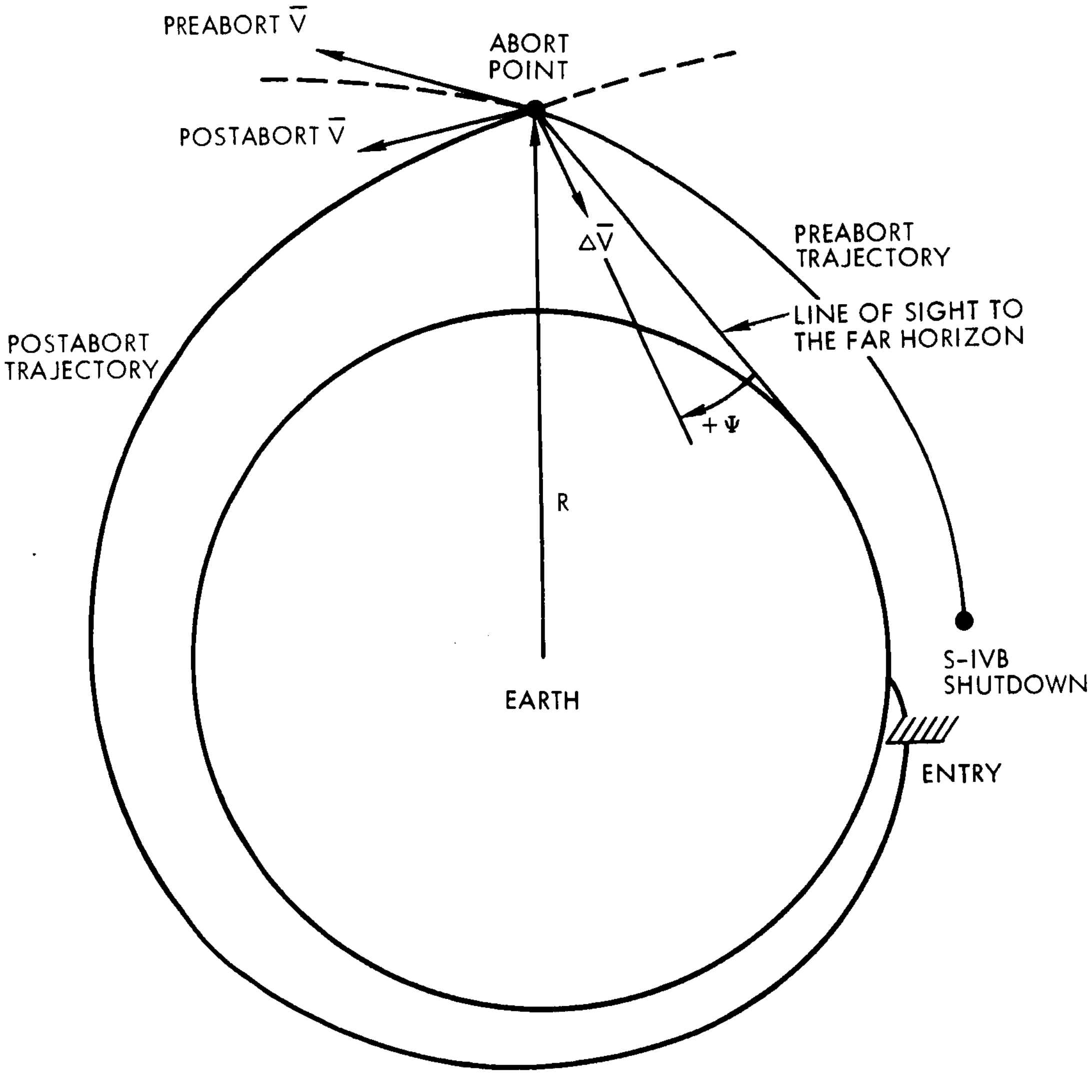

Figure 2-2. Basic Geometry of an Earth Horizon Reference Abort

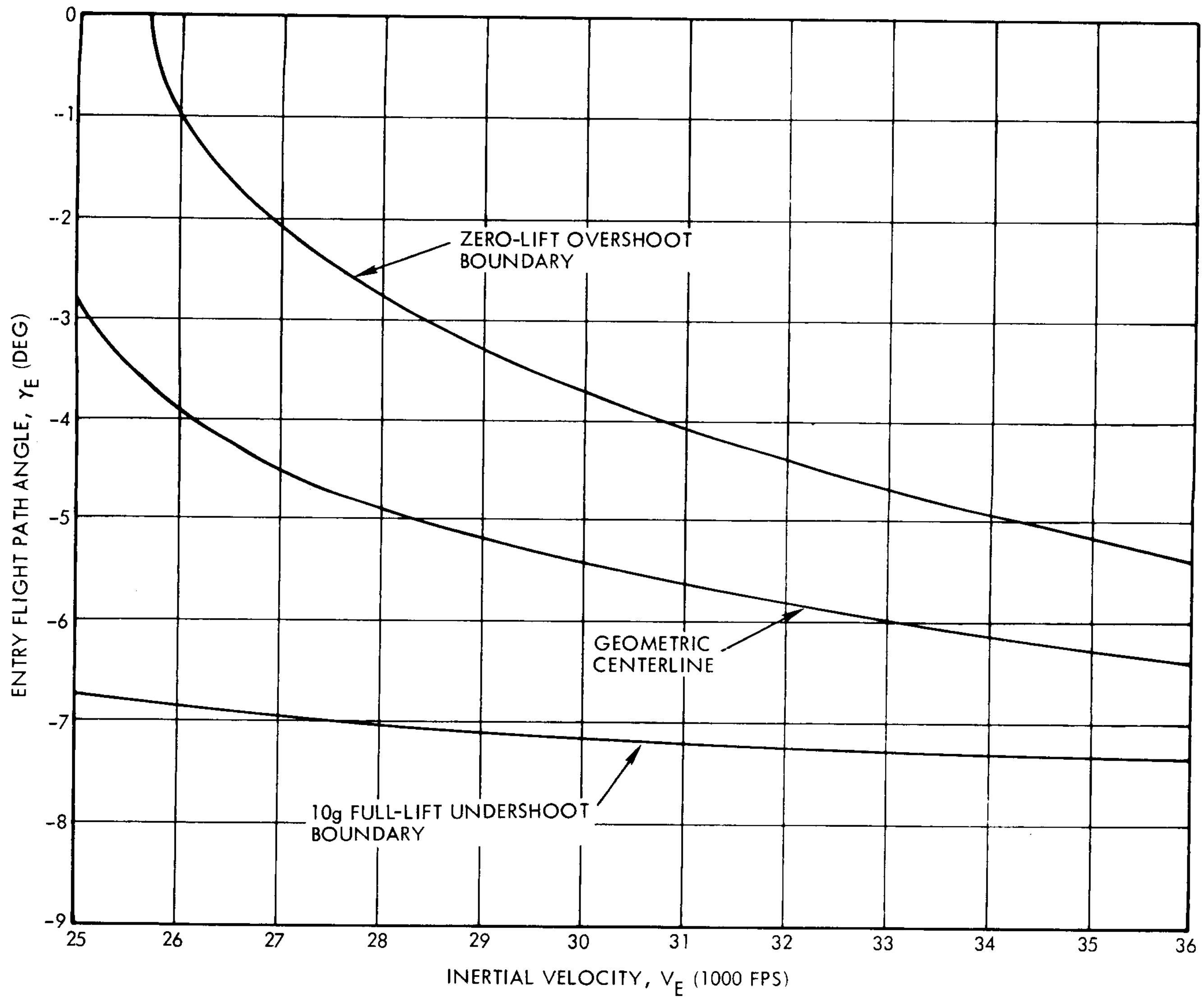

Figure 2-3. The AS-504 Entry Corridor; Entry Flight-path Angle as a Function of Inertial Velocity

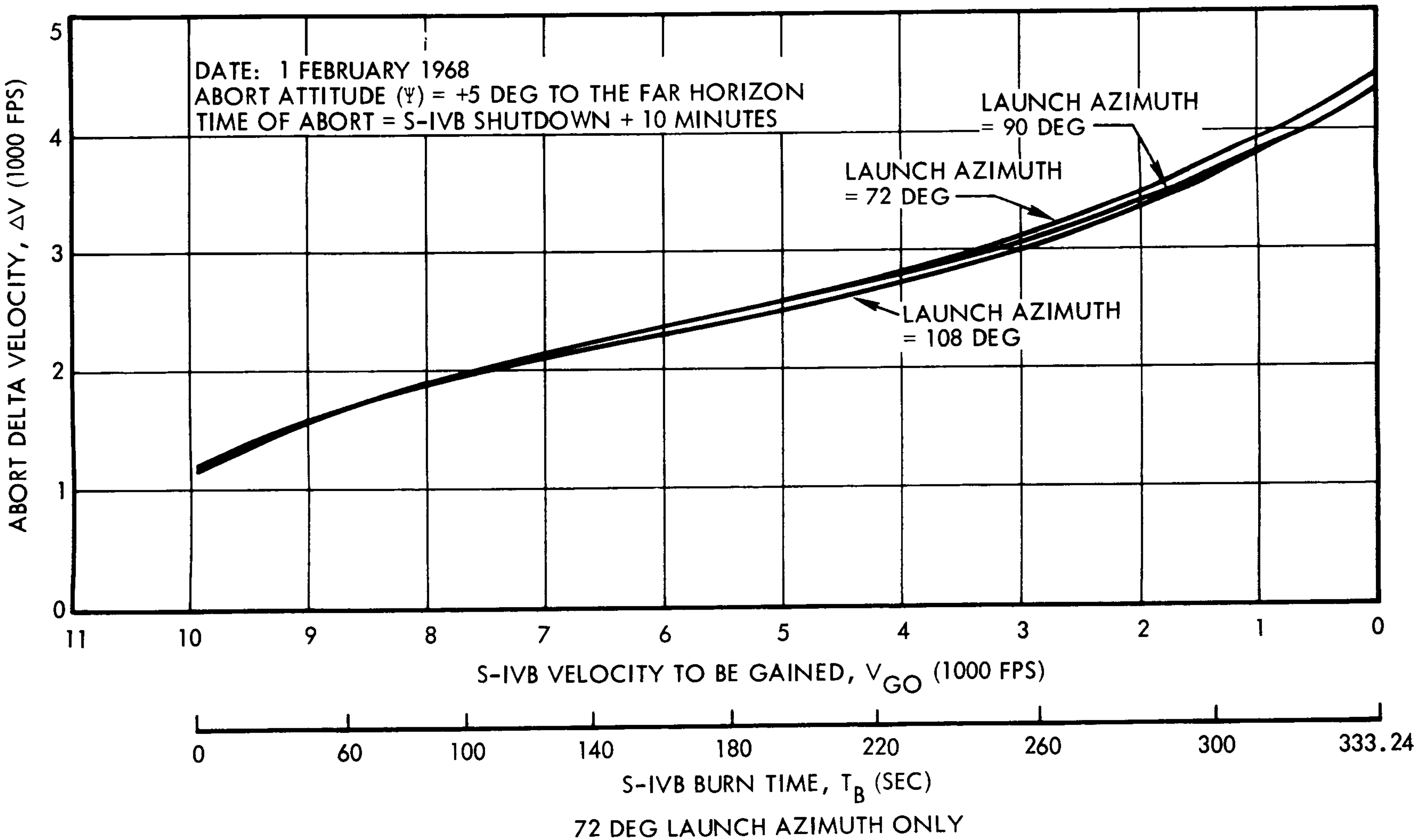

Figure 2-4. Abort Delta Velocity as a Function of S-IVB Velocity to be Gained for 1 February; Launch Azimuths of 72, 90, and 108 Degrees

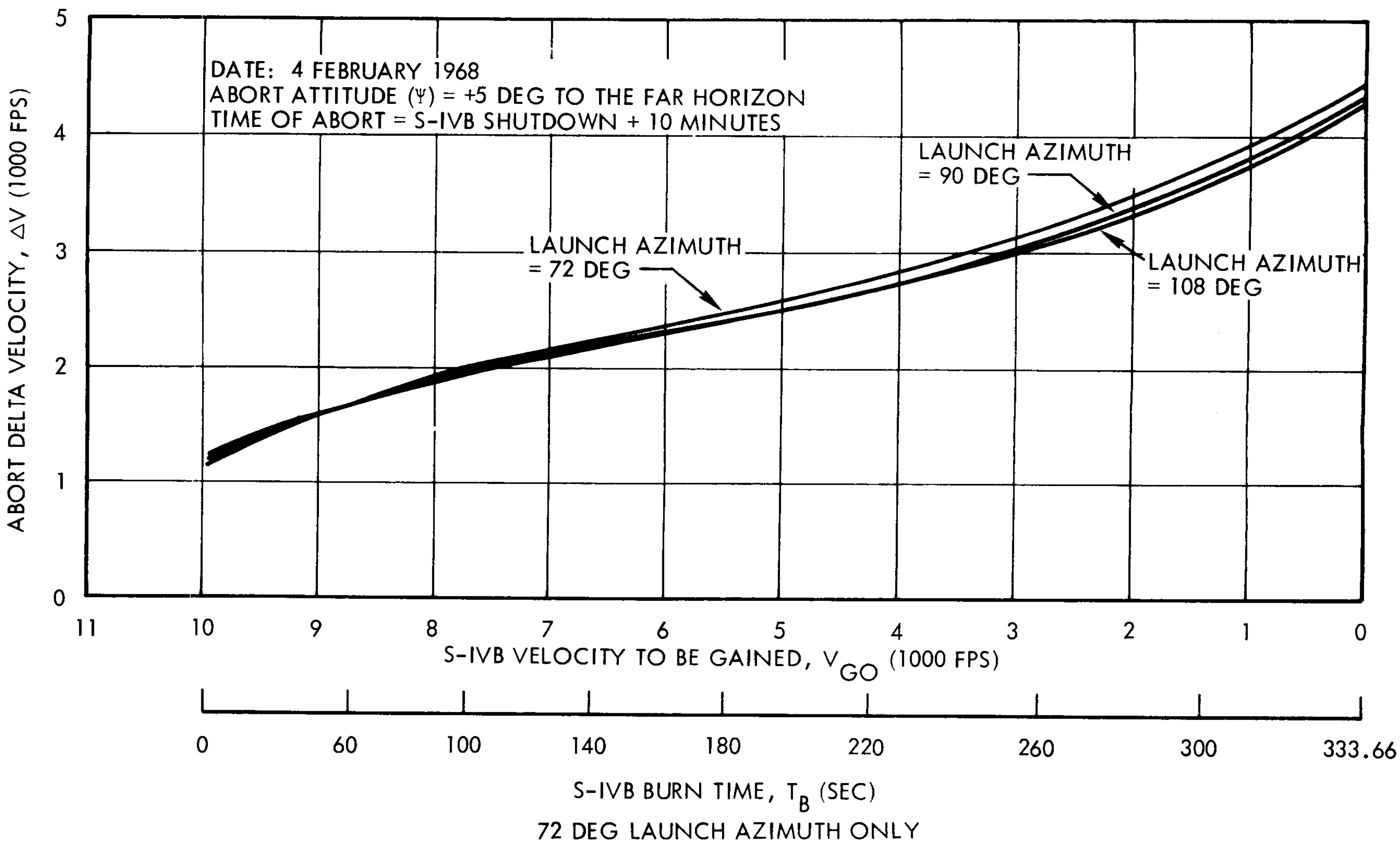

Figure 2-5. Abort Delta Velocity as a Function of S-IVB Velocity to be Gained for 4 February; Launch Azimuths of 72, 90, and 108 Degrees

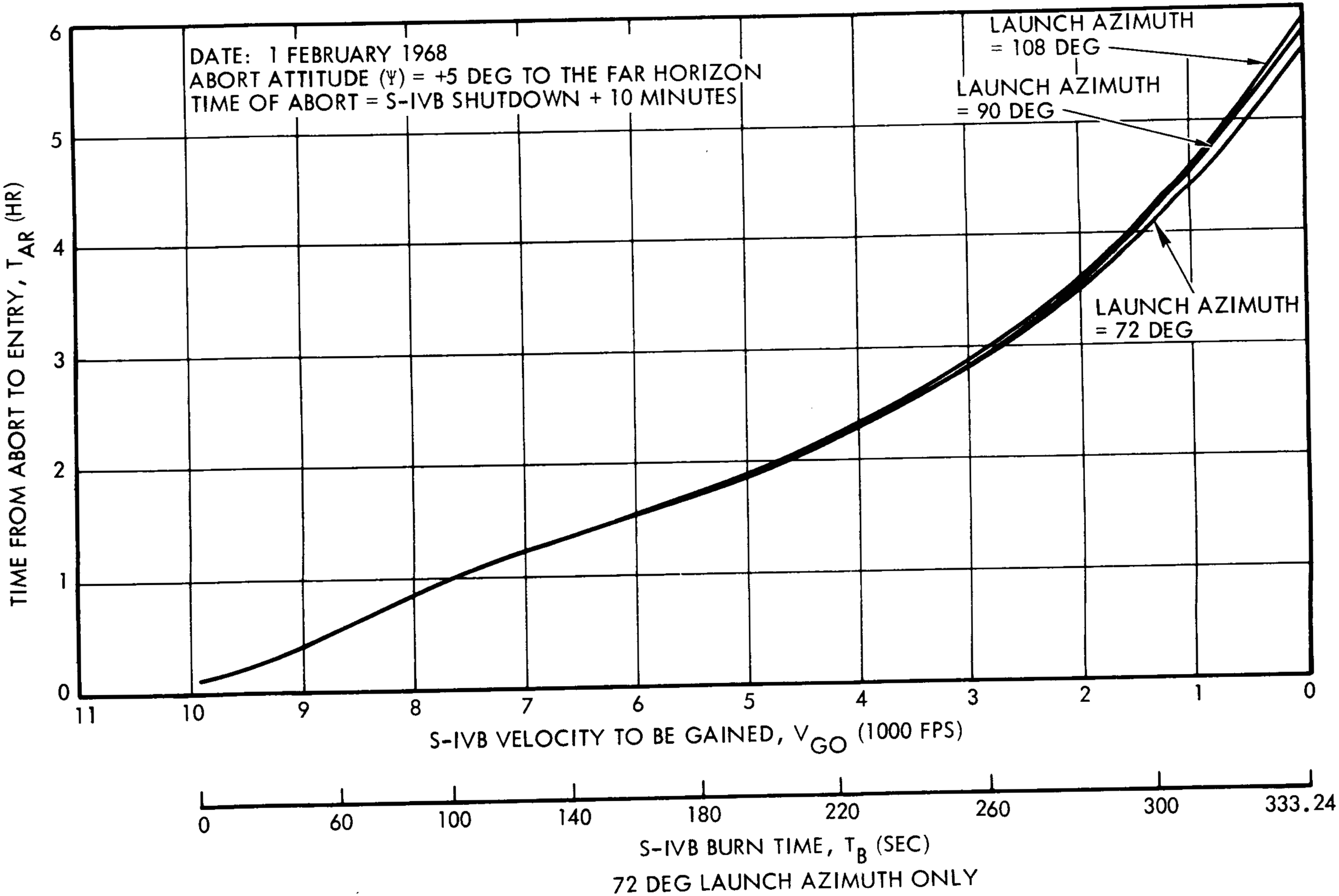

Figure 2-6. Time from Abort to Entry as a Function of S-IVB Velocity to be Gained for 1 February; Launch Azimuths of 72, 90, and 108 Degrees

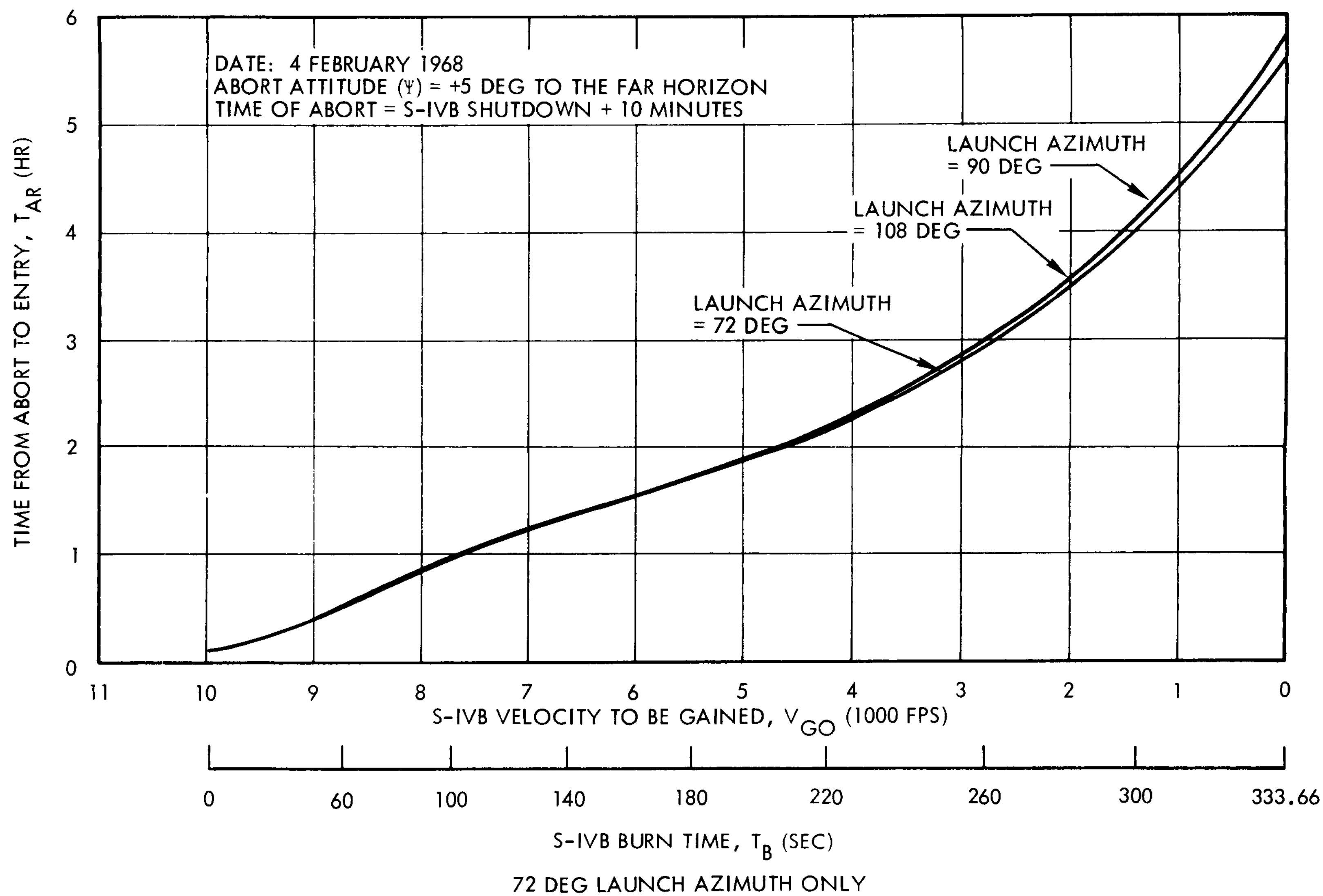

Figure 2-7. Time from Abort to Entry as a Function of S-IVB Velocity to be Gained for 4 February; Launch Azimuths of 72, 90, and 108 Degrees

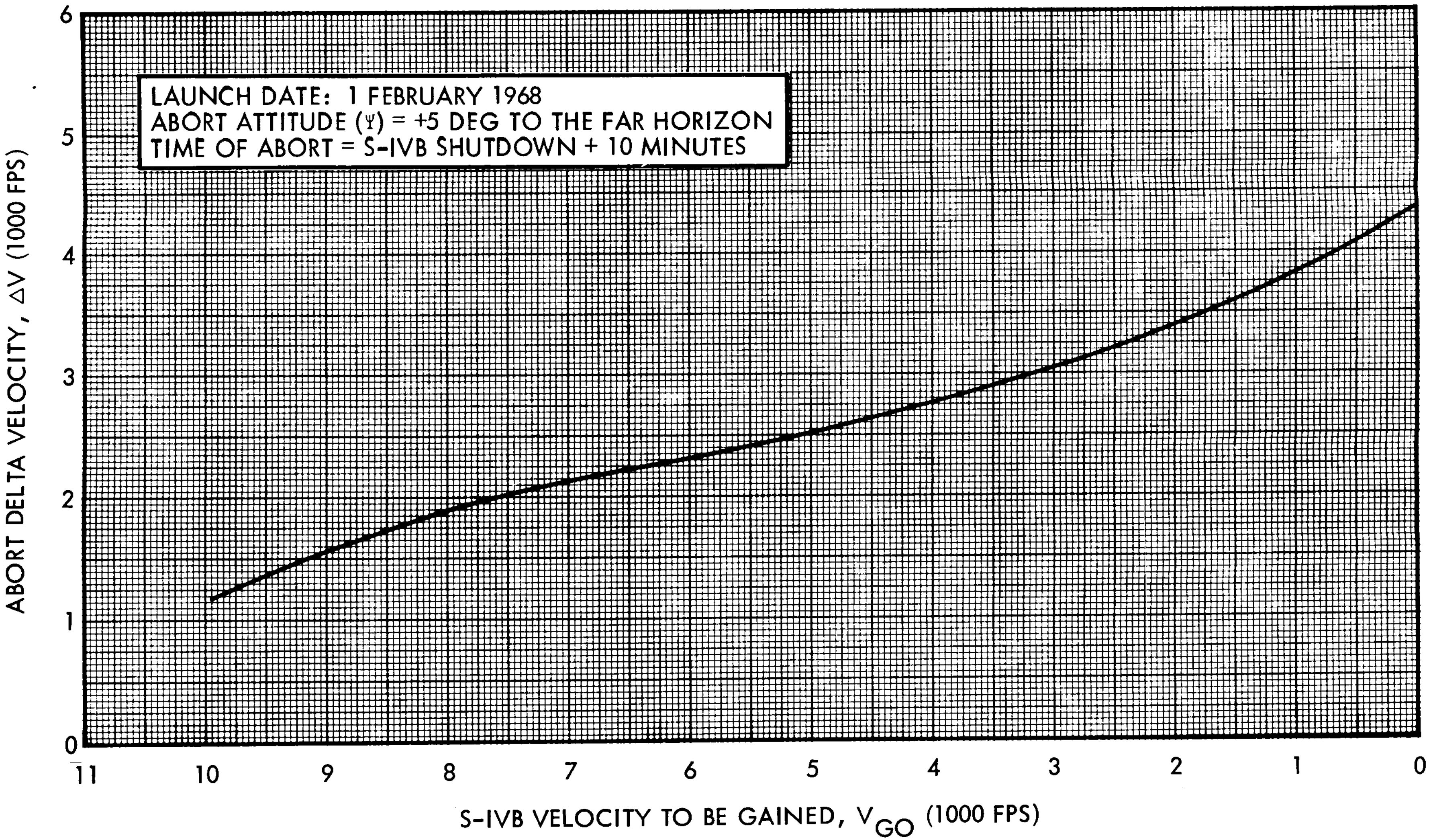

Figure 2-8. A Typical Crew Chart Showing Abort Delta Velocity as a Function of S-IVB Velocity to be Gained for 1 February (The Curve Represents the Mean of the Two Curves Shown in Figure 2-4 for Launch Azimuths of 72 and 108 Degrees.)

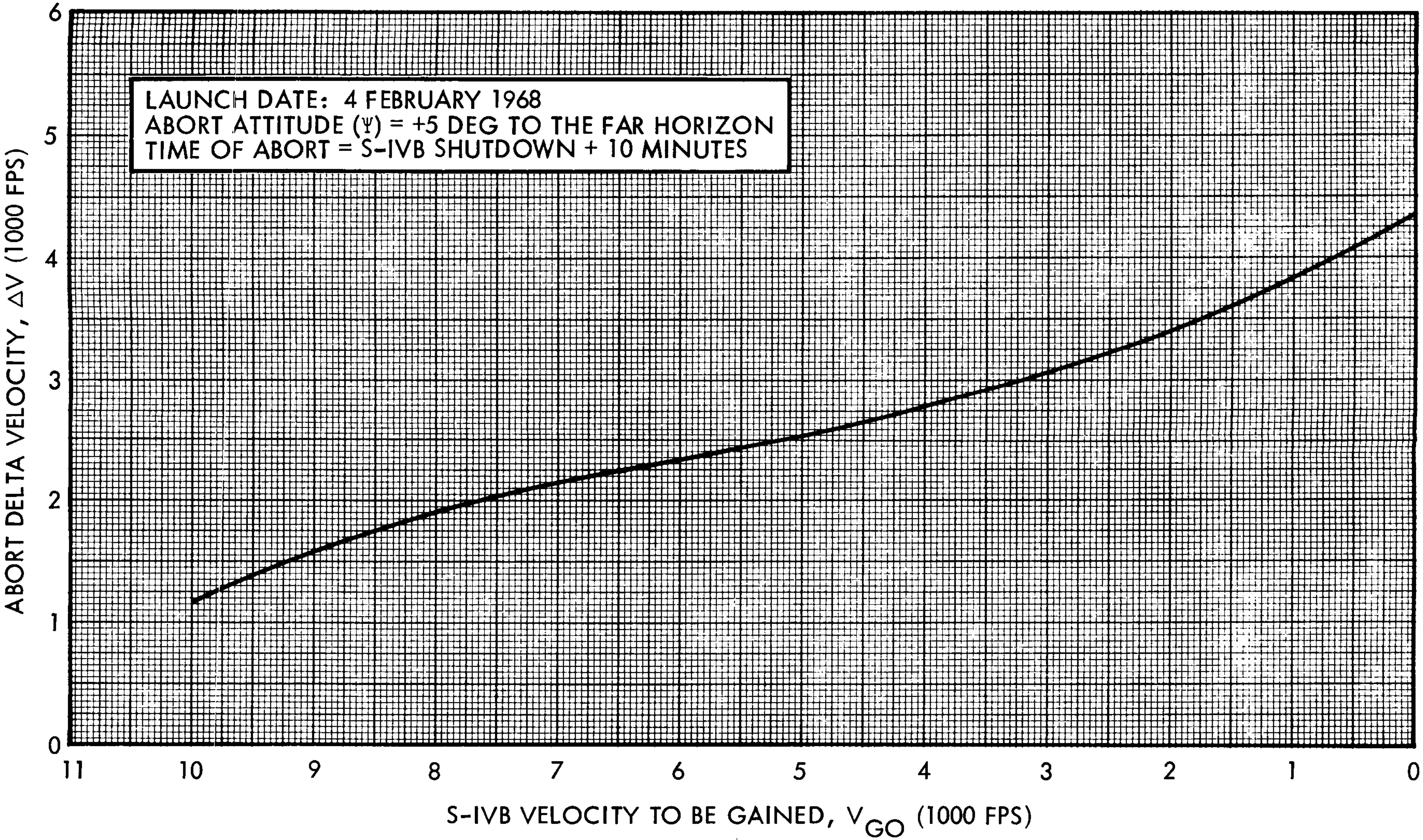

Figure 2-9. A Typical Crew Chart Showing Abort Delta Velocity as a Function of S-IVB Velocity to be Gained for 4 February (The Curve Represents the Mean of the Two Curves Shown in Figure 2-5 for Launch Azimuths of 72 and 108 Degrees.)

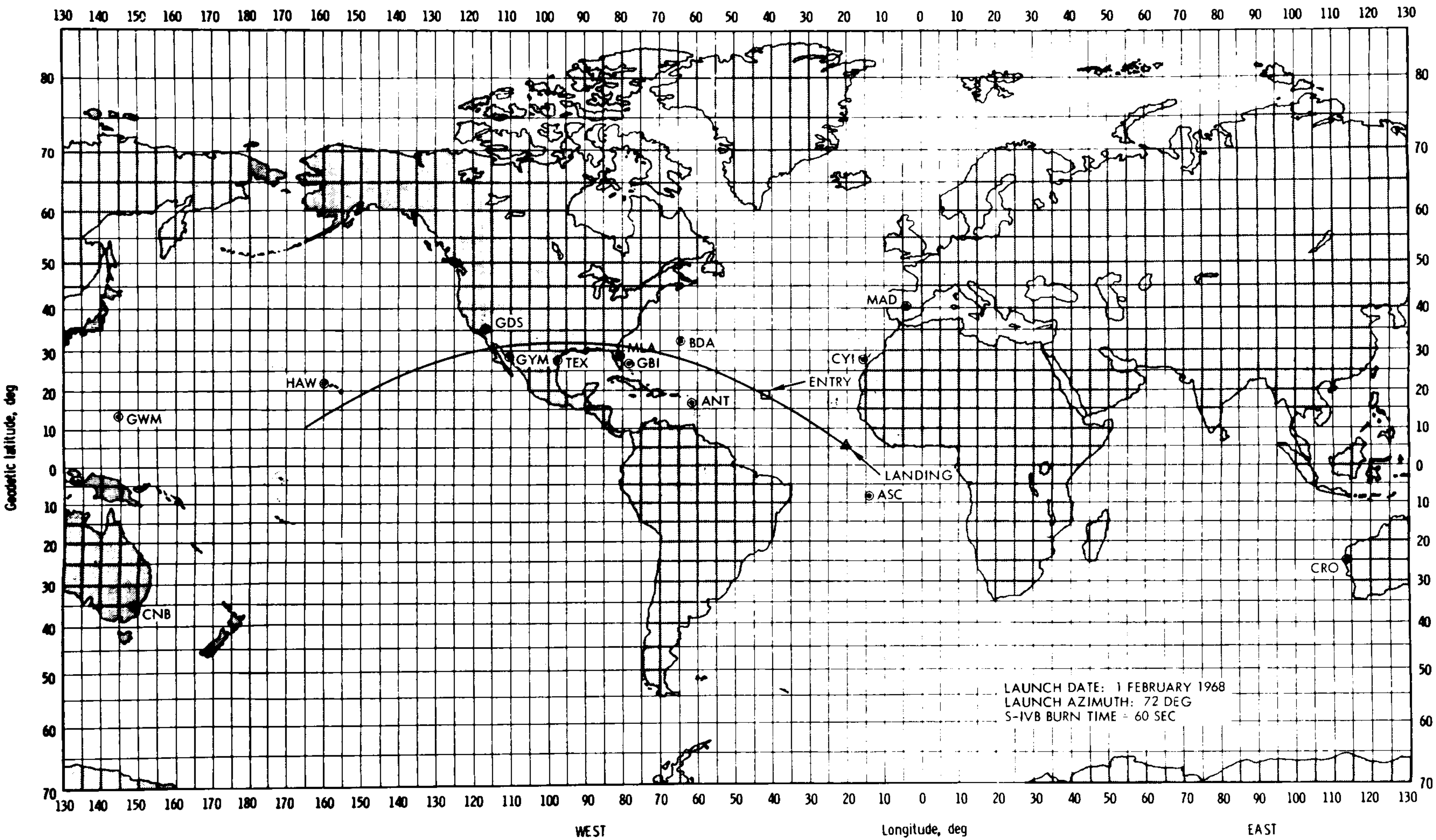

Figure 2-10. Postabort Groundtrack for 1 February; Launch Azimuth of 72 Degrees with a S-IVB Burn Time of 60 Seconds

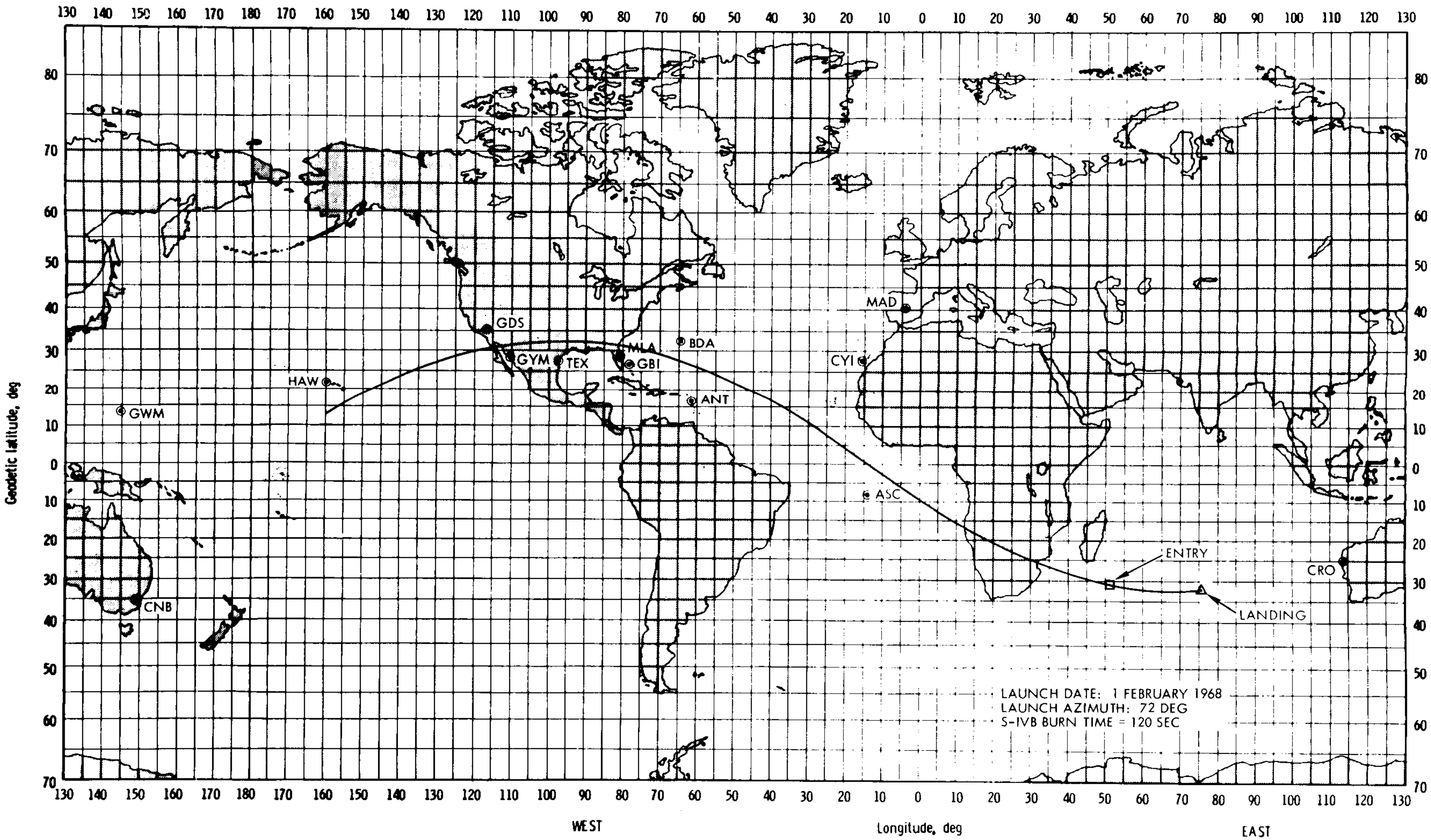

Figure 2-11. Postabort Groundtrack for 1 February; Launch Azimuth of 72 Degrees with a S-IVB Burn Time of 120 Seconds

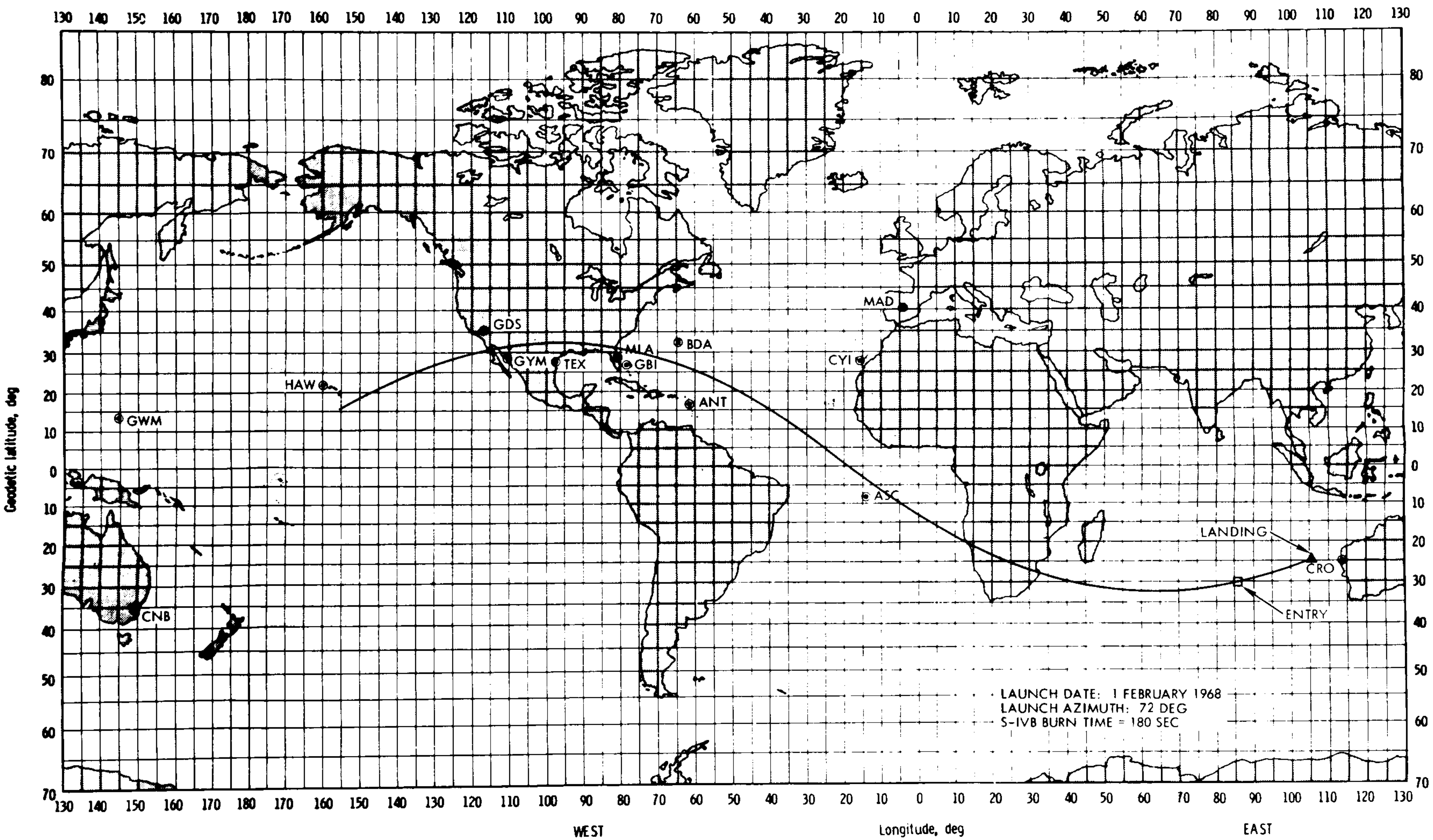

Figure 2-12. Postabort Groundtrack for 1 February; Launch Azimuth of 72 Degrees with a S-IVB Burn Time of 180 Seconds

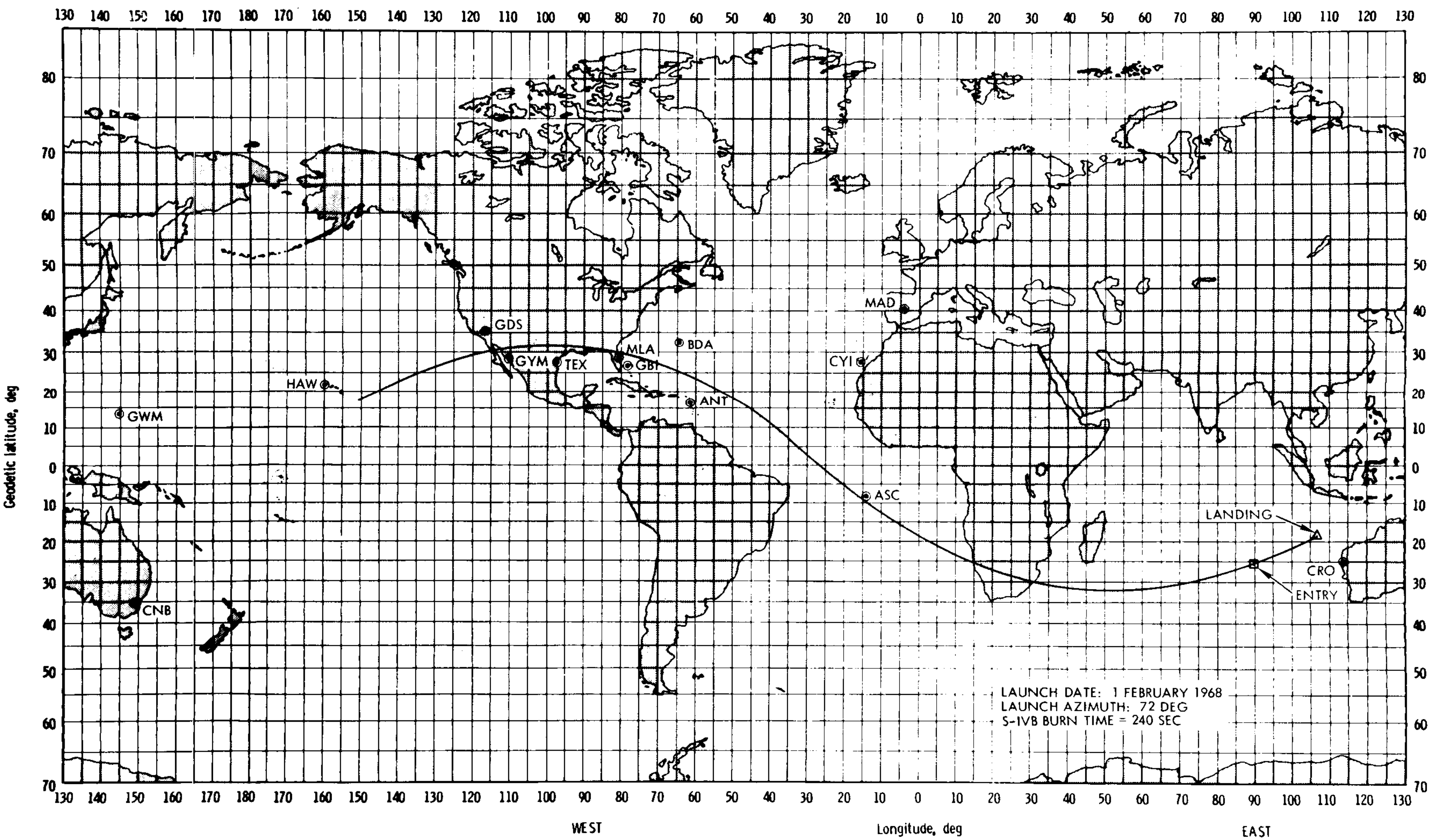

Figure 2-13. Postabort Groundtrack for 1 February; Launch Azimuth of 72 Degrees with a S-IVB Burn Time of 240 Seconds

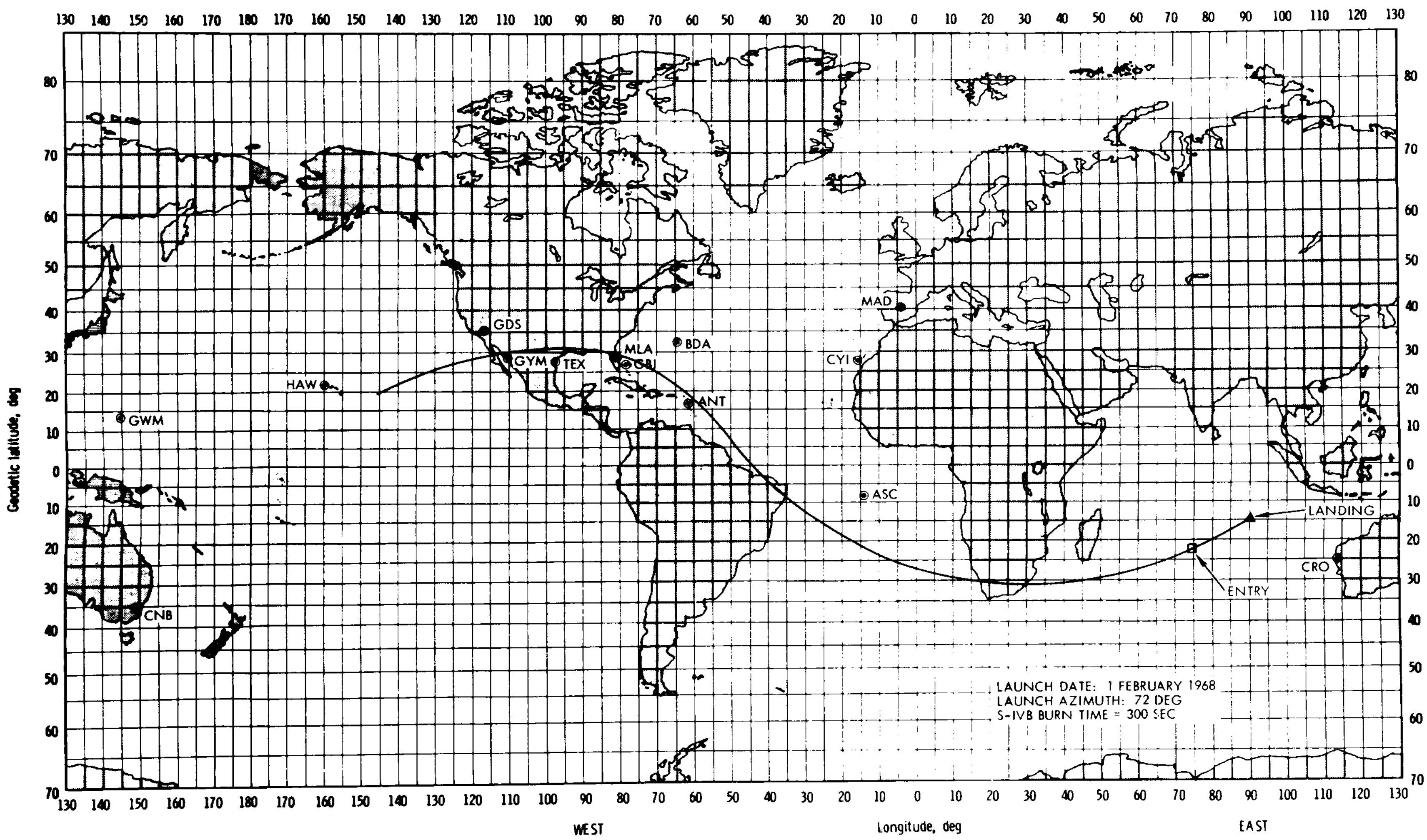

Figure 2-14. Postabort Groundtrack for 1 February; Launch Azimuth of 72 Degrees with a S-IVB Burn Time of 300 Seconds

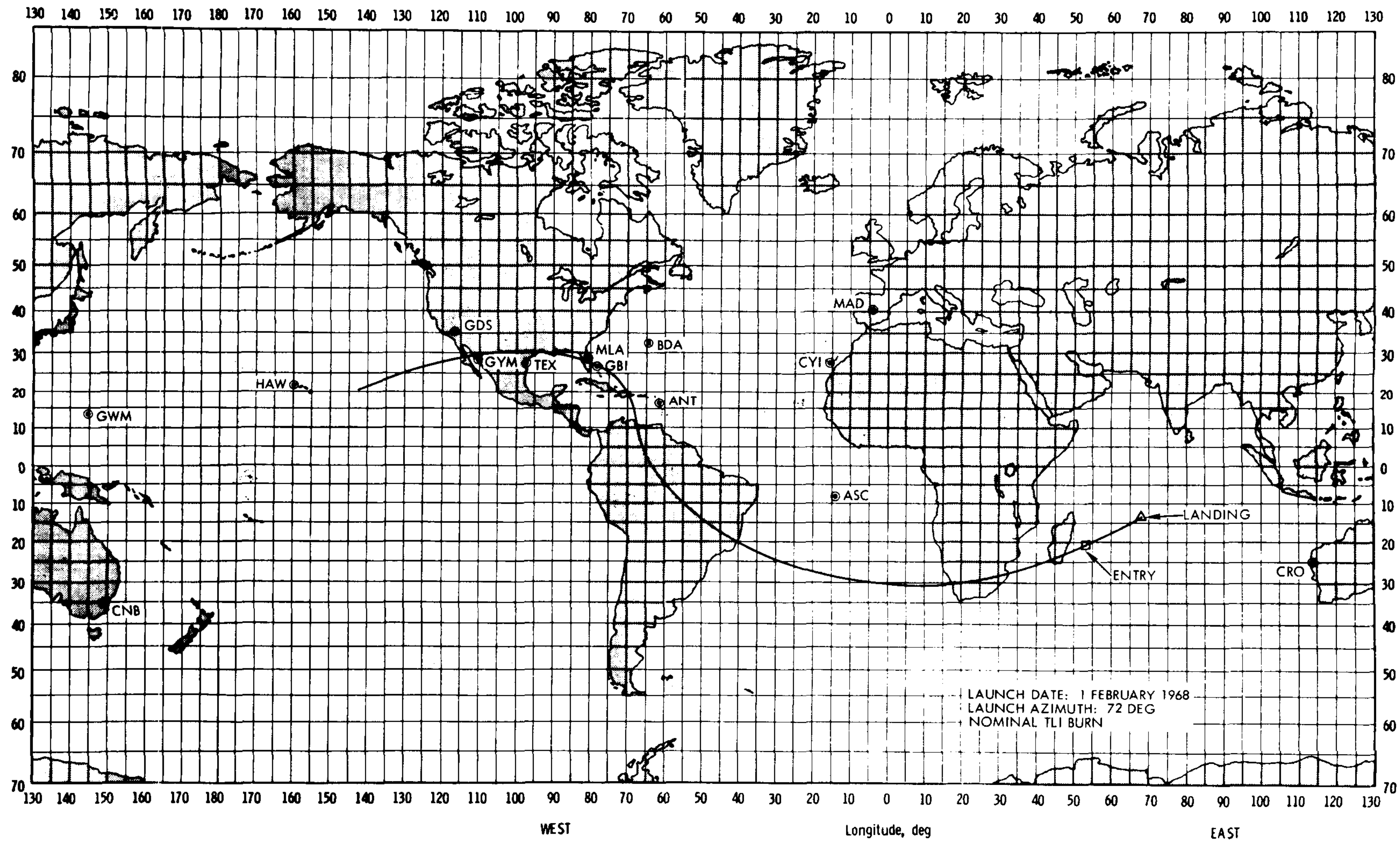

Figure 2-15. Postabort Groundtrack for 1 February; Launch Azimuth of 72 Degrees for the Nominal TLI Burn

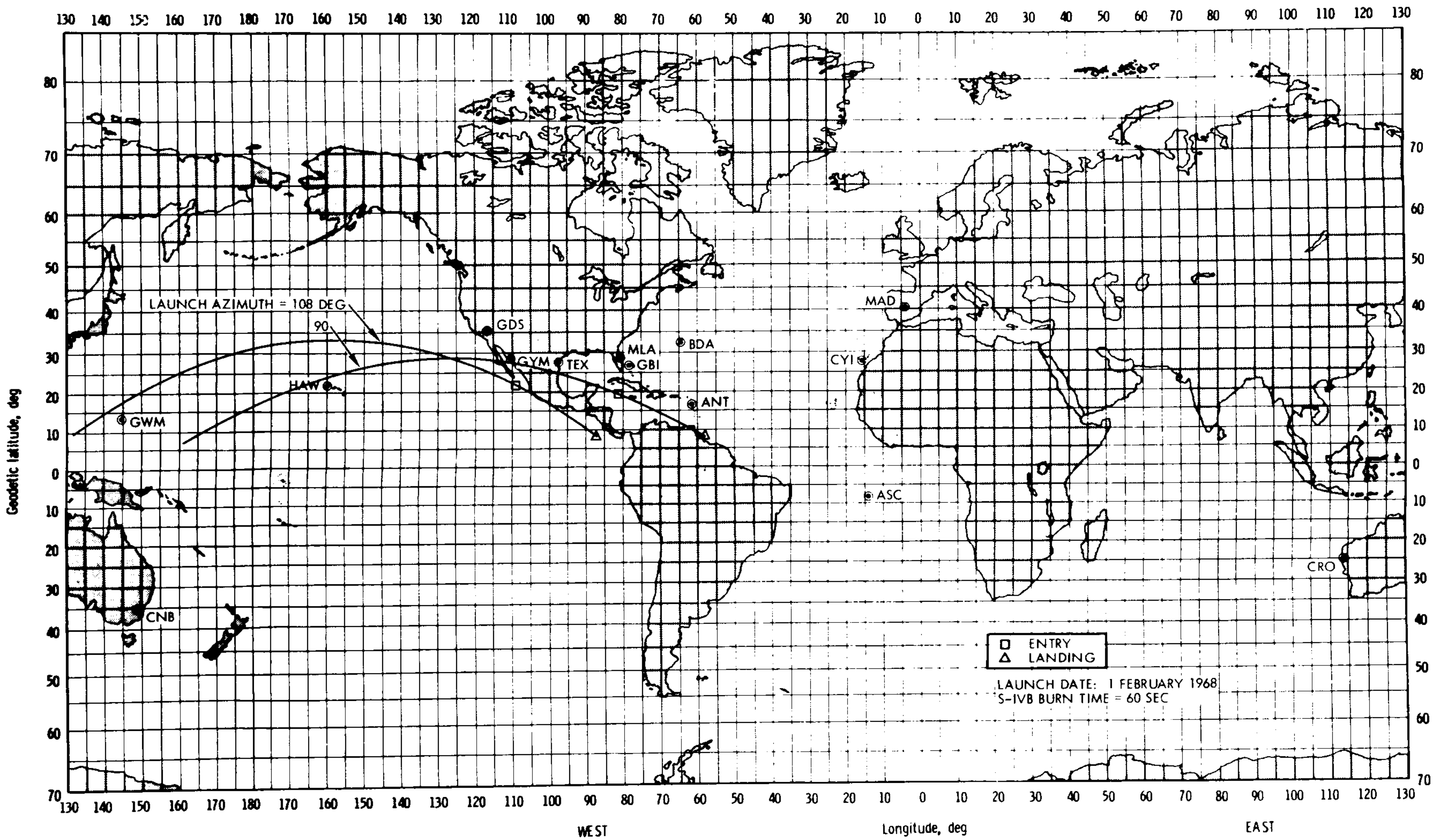

Figure 2-16. Postabort Groundtrack for 1 February; Launch Azimuths of 90 and 108 Degrees with a S-IVB Burn Time of 60 Seconds

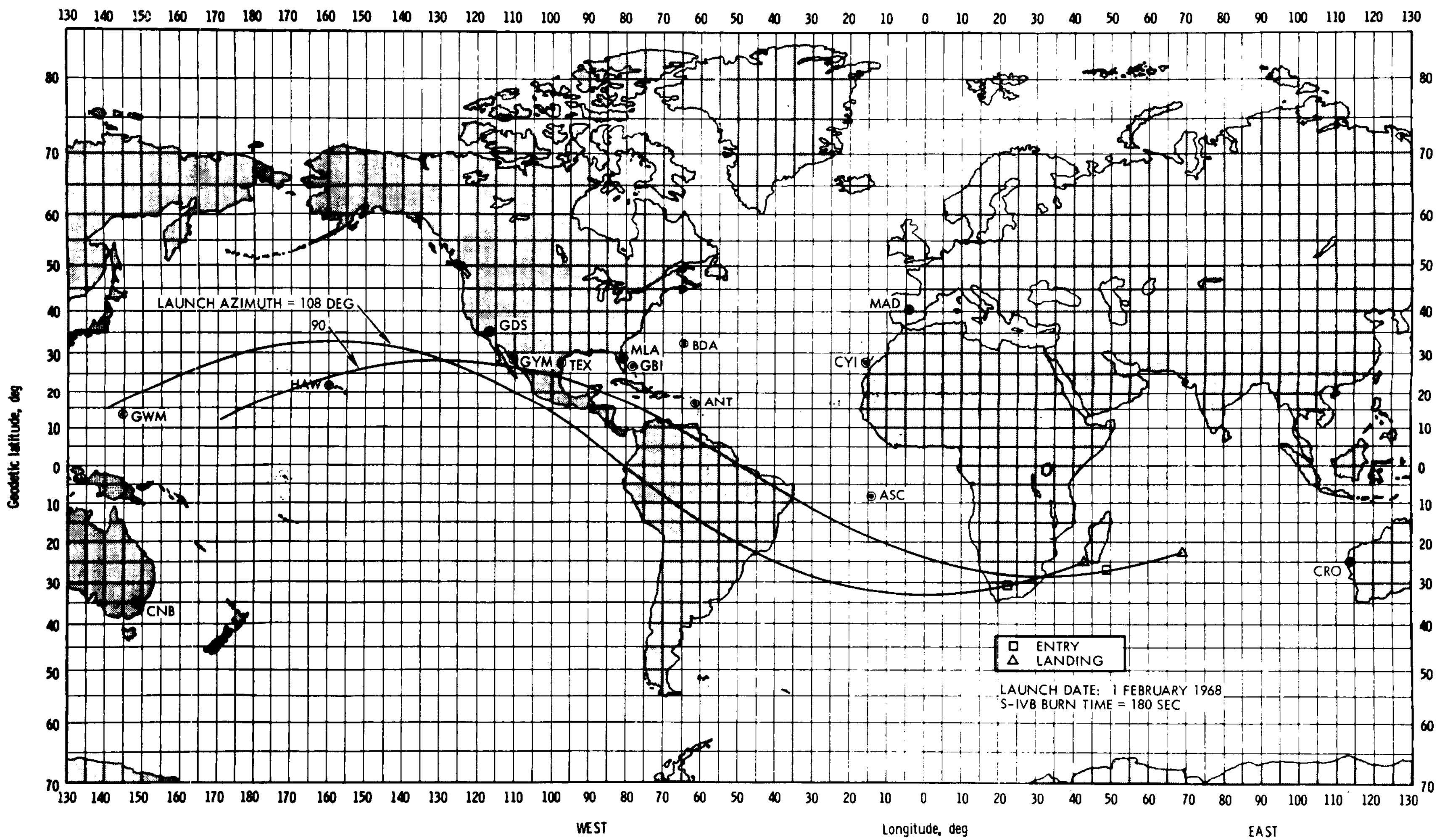

Figure 2-17. Postabort Groundtrack for 1 February; Launch Azimuths of 90 and 108 Degrees with a S-IVB Burn Time of 180 Seconds

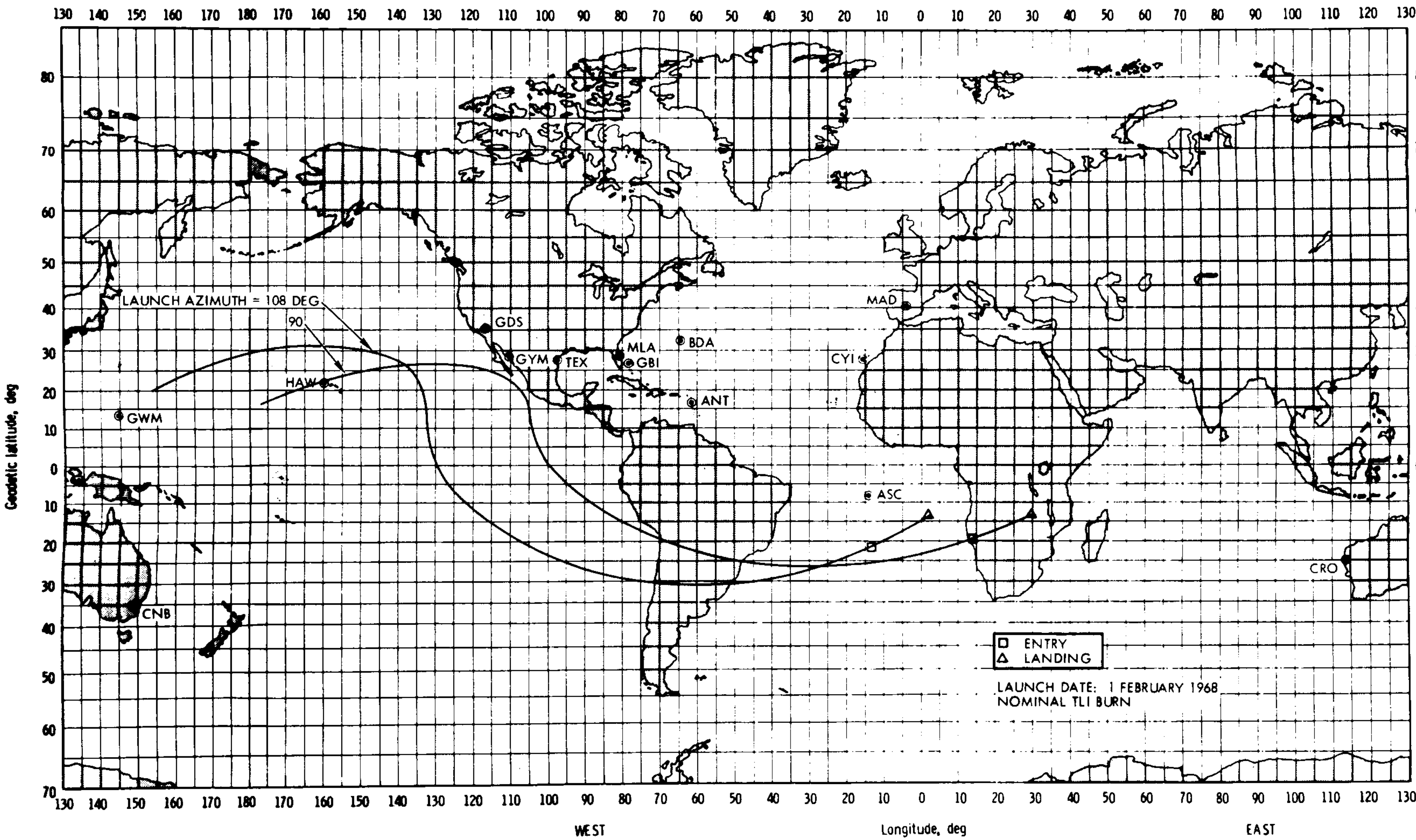

Figure 2-18. Postabort Groundtrack for 1 February; Launch Azimuths of 90 and 108 Degrees for the Nominal TLI Burn

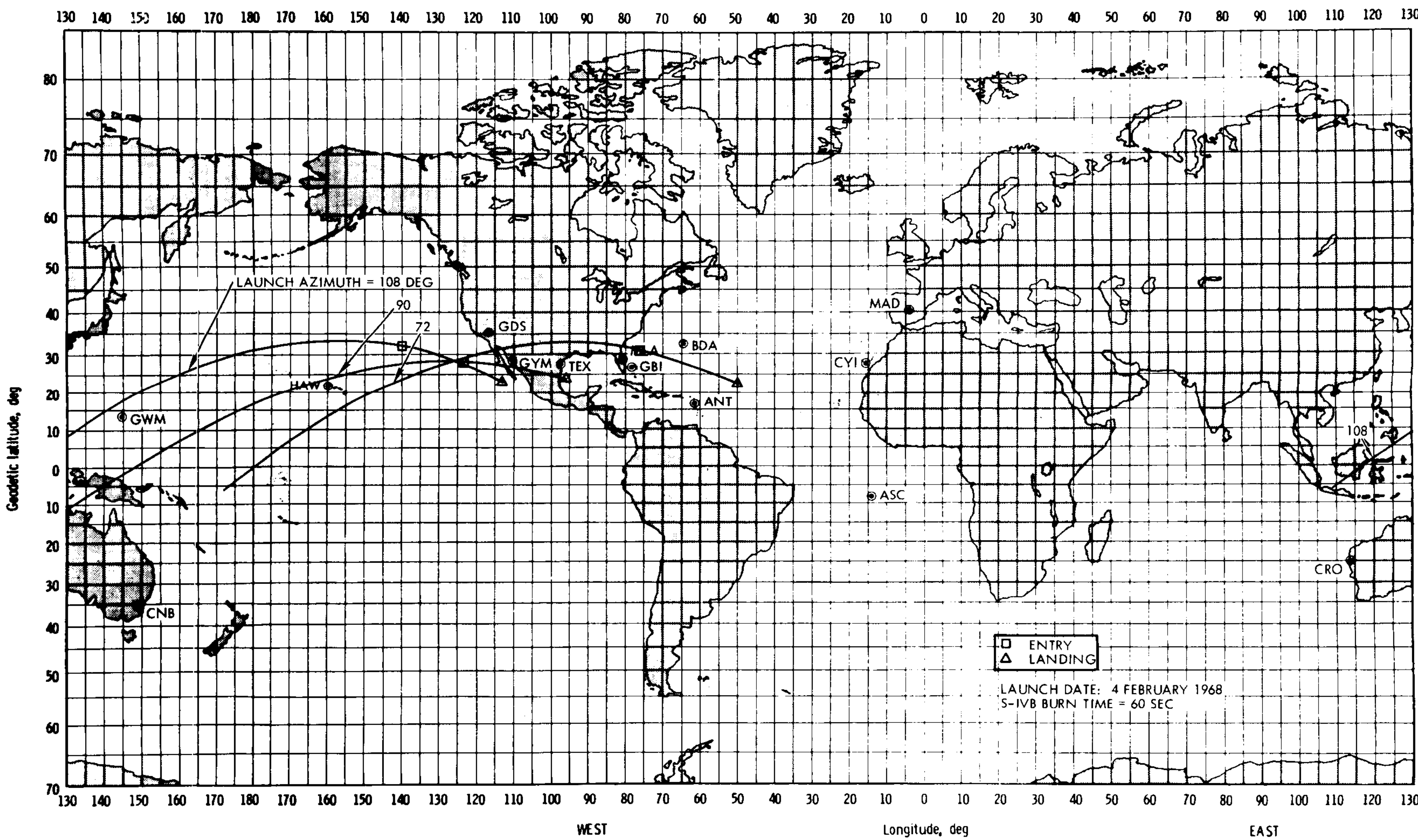

Figure 2-19. Postabort Groundtrack for 4 February; Launch Azimuths of 72, 90, and 108 Degrees with a S-IVB Burn Time of 60 Seconds

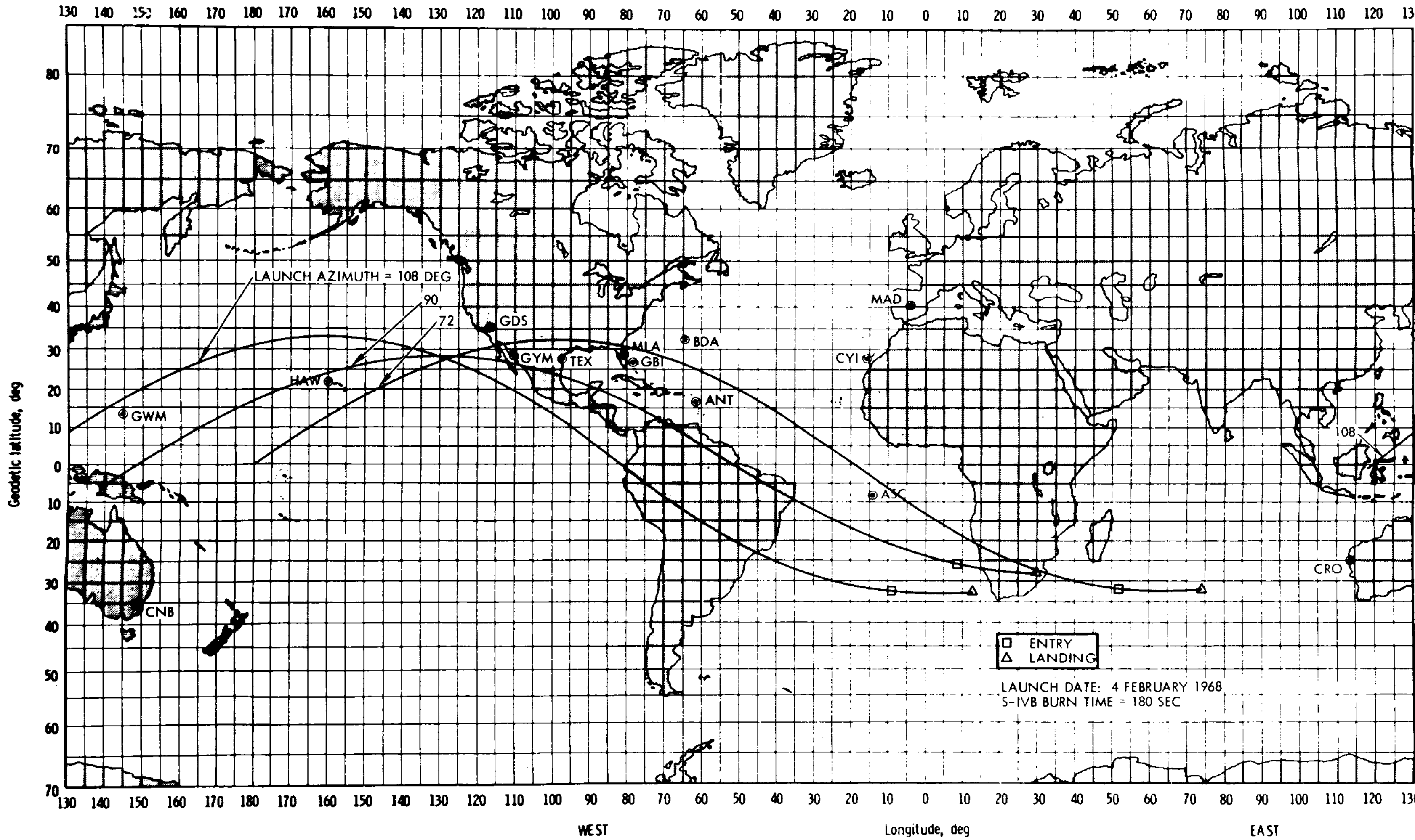

Figure 2-20. Postabort Groundtrack for 4 February; Launch Azimuths of 72, 90, and 108 Degrees with a S-IVB Burn Time of 180 Seconds

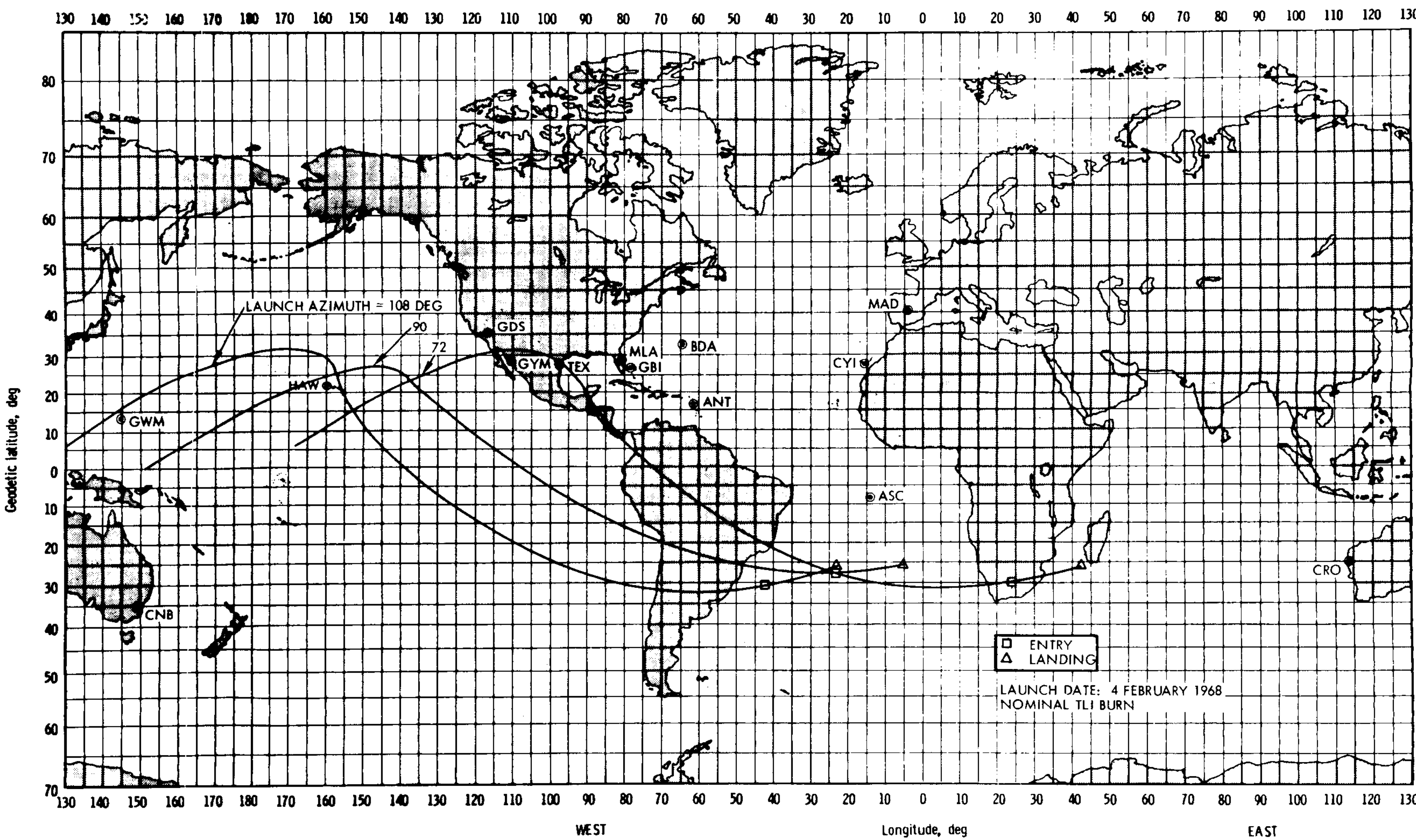

Figure 2-21. Postabort Groundtrack for 4 February; Launch Azimuths of 72, 90, and 108 Degrees for the Nominal TLI Burn

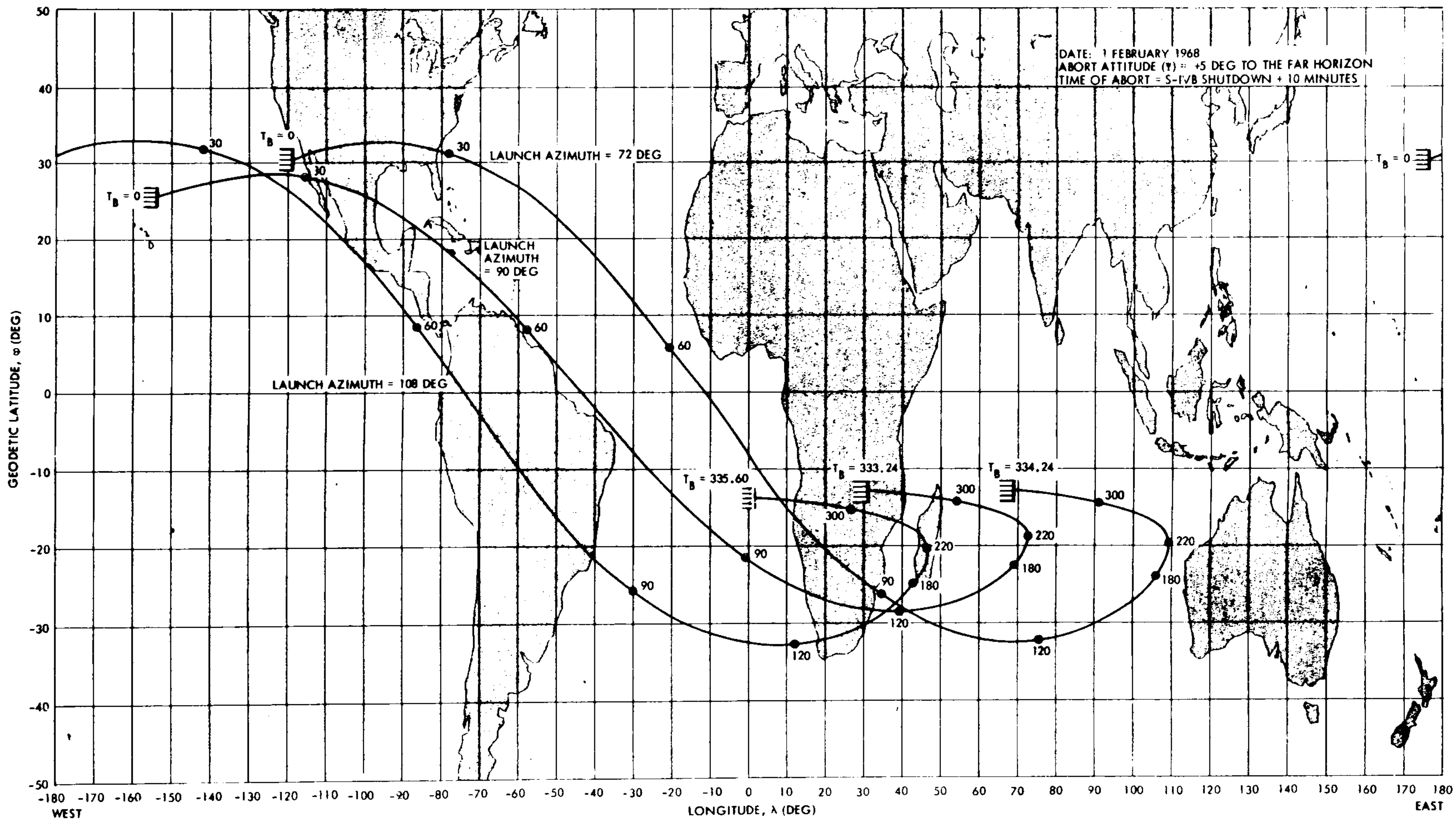

Figure 2-22. Trace of Landing Points for 1 February; Launch Azimuths of 72, 90, and 108 Degrees

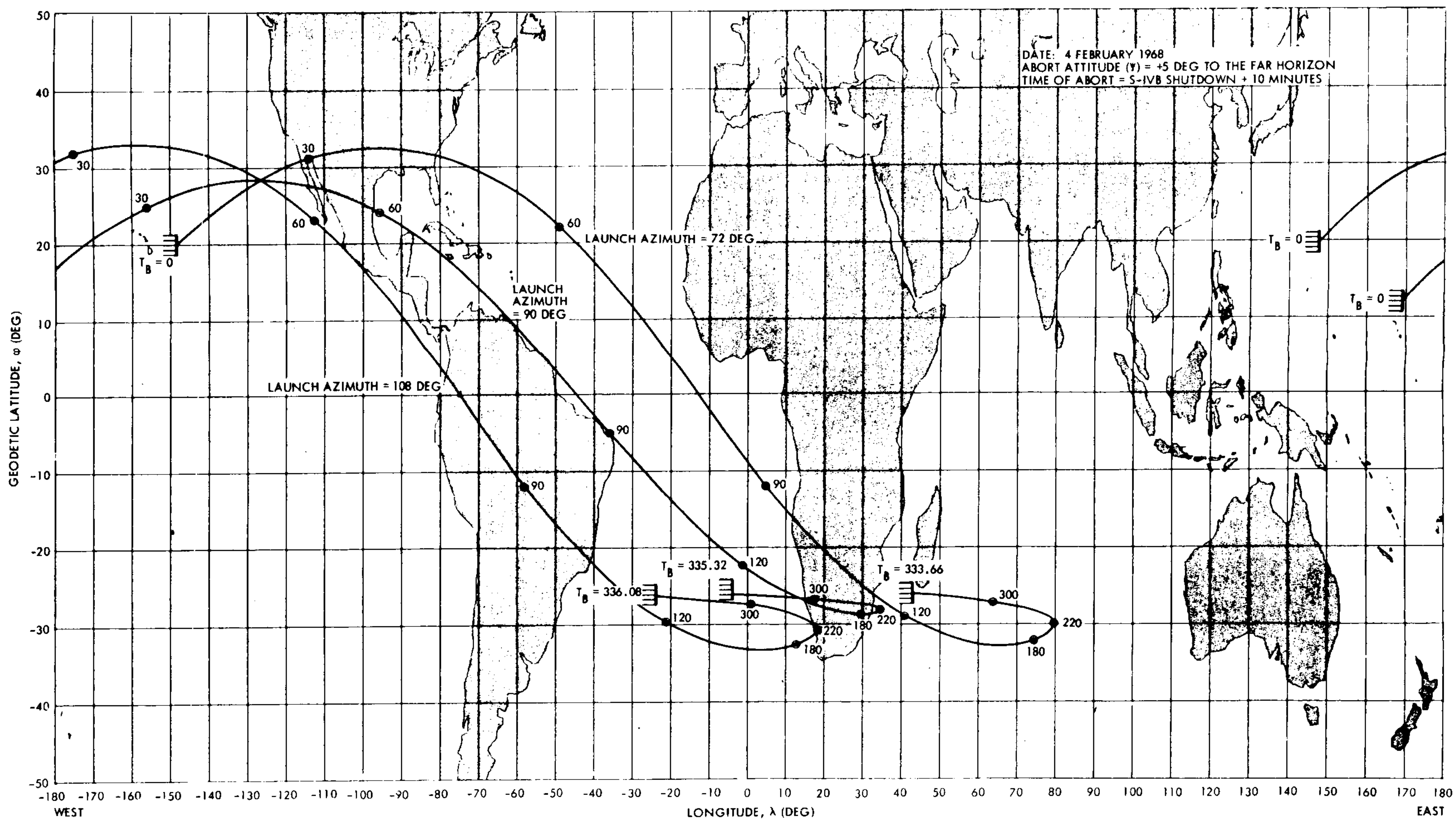

Figure 2-23. Trace of Landing Points for 4 February; Launch Azimuths of 72, 90, and 108 Degrees

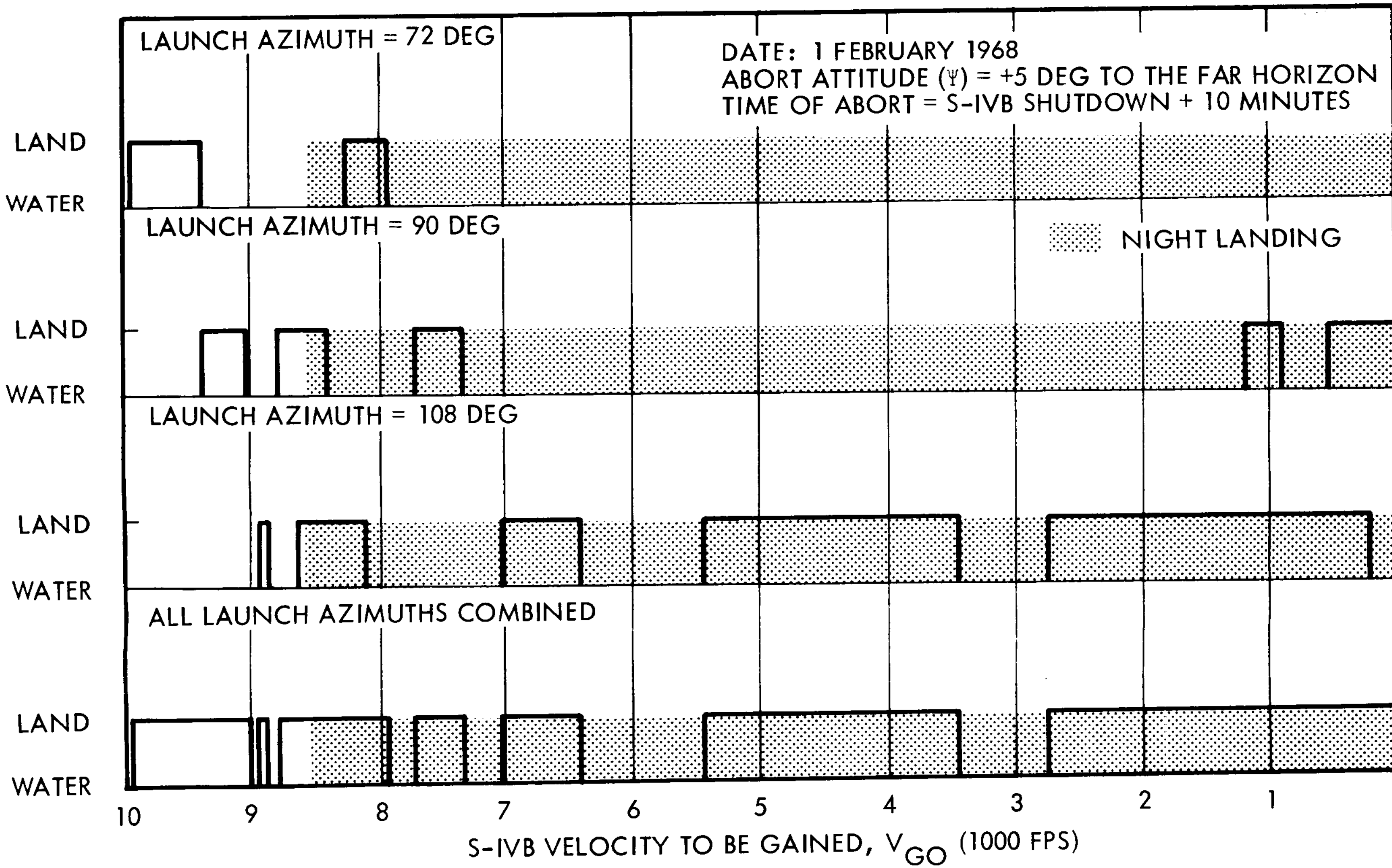

Figure 2-24. Distribution of Water and Land Landings with Lighting Conditions Indicated as a Function of S-IVB Velocity to be Gained for Launch Azimuths of 72, 90, and 108 Degrees and all Launch Azimuths Combined on 1 February

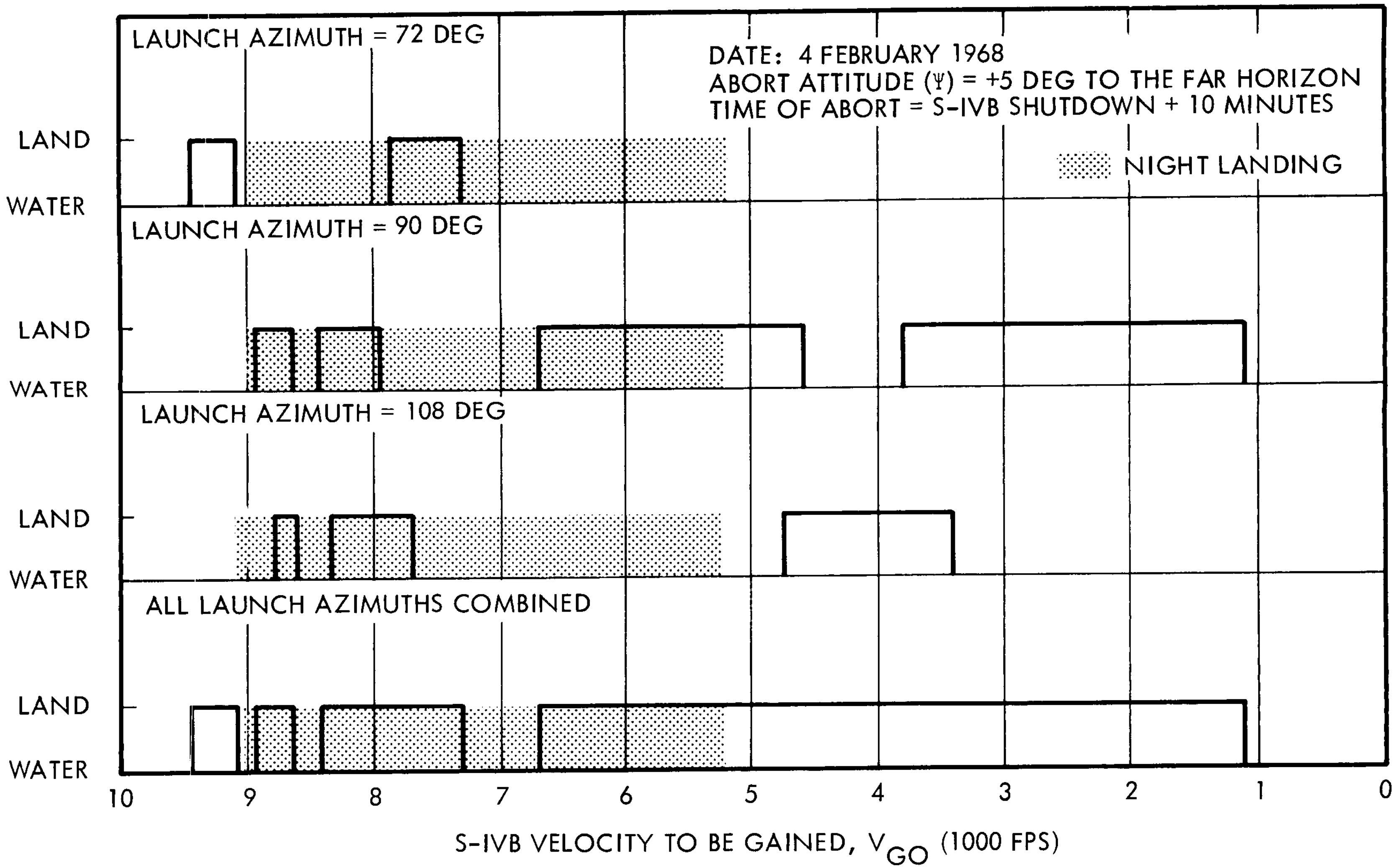

Figure 2-25. Distribution of Water and Land Landings with Lighting Conditions Indicated as a Function of S-IVB Velocity to be Gained for Launch Azimuths of 72, 90, and 108 Degrees and all Launch Azimuths Combined on 4 February

3. MIDCOURSE MANEUVERS

3.1 GENERAL

The fixed-attitude abort maneuvers discussed in Section 2 were targeted to the geometric centerline of the entry corridor shown in Figure 2-3. It has been shown in previous studies (References 4 and 7), however, that inaccuracies in thrust vector alignment at the time of abort can result in entry conditions which deviate appreciably from the target line. These alignment errors can be due to SCS pointing errors, initial attitude alignment errors, or both.

It is the current intent that all deviations from the target line will be corrected whenever possible with a midcourse maneuver. The midcourse requirement will be operationally limited by the constraints of some minimum preparation time, a minimum allowable time from midcourse to entry, and perhaps by a lower limit to the fuel expenditure below which a midcourse maneuver is not necessary. It is planned that the maneuver itself will always be an SPS burn, with RCS trim if necessary. The Return to Earth Abort Processor (RTEAP) will be used to compute the solution in the RTCC or, in the absence of communications, the onboard processor using guidance and navigation (G&N) data can be used. All midcourse solutions will be targeted back to the corridor centerline using the γ_E override presently planned for both the onboard and RTCC systems.

3.2 DISCUSSION

Data for the midcourse maneuver analysis were generated using the TLI burn occurring on 1 February 1968 with a launch azimuth of 72 degrees as a typical case. The fixed-attitude, fixed-delay time abort procedure discussed in Section 2 (T_D = 10 minutes, heads up, Ψ = 5 degrees) was applied at several S-IVB times, with the abort maneuver being targeted to the geometrical centerline of the entry corridor. Trajectories experiencing deviations from the target line were produced by introducing pitch errors, $\Delta\beta$, of plus or minus 3 degrees to the abort maneuver. A 1-degree alignment error is representative of the expected SCS pitch error during the execution of the abort maneuver. Since the initial attitude alignment is to be made by the crew using visual reference techniques, however, a

3-degree error is a better estimate of the total pitch misalignment incurred during the abort maneuver (Reference 8). Yaw errors were neglected since the fixed-attitude abort is an inplane maneuver, and it is known (Reference 7) that inplane maneuvers are very insensitive to deviations in yaw. Errors in the ΔV magnitude also were ignored, since the abort maneuver has been demonstrated to be insensitive to much larger ΔV deviations than those expected during an SCS burn (Reference 7 and Section 2.4).

The effect that pitch errors of plus or minus 3 degrees have on entry conditions can be seen in Figure 3-1, in which the entry corridor shown is the same as that in Figure 2-3. The vertical dashed lines connecting the two lines of constant $\Delta\beta$ are lines of constant S-IVB burn time. It is evident from the figure that aborts performed with pitch errors of plus or minus 3 degrees result in entry conditions which deviate appreciably from the target line, even at the lowest burn times. The abort maneuver with $\Delta\beta$ = -3 degrees has entry conditions which lie outside the corridor for S-IVB burn times greater than 270 seconds, while the maneuver with $\Delta\beta$ = +3 degrees is outside the corridor shortly after a 240-second S-IVB burn time. If the corridor boundaries are interpreted as survival limits, it is imperative that abort maneuvers which produce entry conditions outside the corridor be corrected with a midcourse maneuver. Even for the other burn times, deviations from the target line are so large that a midcourse correction should be performed whenever possible. This is in agreement with the opinion that all fixed-attitude aborts resulting in non-nominal entry conditions will be followed by a midcourse maneuver targeted back to the original target line, whenever possible.

Operational considerations prohibit the use of midcourse corrections on postabort trajectories which exhibit times from abort to entry less than approximately 1.5 hours. The 1.5-hour value is not to be taken as a firm constraint and could be increased or decreased depending on the final requirements defined for midcourse maneuver preparation time, CM/SM separation time, and entry preparation time. It is evident that the time allotted for maneuver preparation should be as large as possible in the event that onboard orbit determination or other time-consuming tasks must be performed. The desire has been expressed to increase the allowable preparation time from 1.0 hour to 1.5 hours, thereby giving a total time of 2.0 hours from abort to entry. This value for maneuver preparation time will limit the possibility of midcourse corrections to only those trajectories having times from abort to entry in excess of approximately 2.0 hours. Regardless of the maneuver preparation time, it is assumed that one-half hour is required to perform the maneuver, CM/SM separation, equipment stowage, and orientation to the proper attitude prior to entry.

The effect that a minimum time from abort to entry constraint has on midcourse requirements can best be understood by examining Figures 3-1 and 3-2. Figure 3-2 presents the time from abort to entry, T_{AR}, as a function of S-IVB burn time, T_B, for fixed-attitude aborts with pitch errors of plus or minus 3 degrees. From this figure it can be seen that if the minimum T_{AR} constraint is defined as 1.5 hours, sufficient time exists to perform the midcourse maneuver only for aborts associated with S-IVB burn times in excess of approximately 160 seconds. If the constraint is raised to 2.0 hours, the minimum time below which midcourses are impossible increases to approximately 210 seconds. Referring back to Figure 3-1, it can be seen that at T_B = 210 seconds, the dispersed entry conditions are near the overshoot boundary with a pitch error of plus 3 degrees, and for burn times just slightly higher a midcourse maneuver must be performed. If the minimum T_{AR} constraint is placed at 1.5 hours, although aborts from trajectories with S-IVB burn times below 160 seconds cannot be corrected, their entry conditions are well within the corridor limits.

Postabort state vectors for the fixed-attitude abort maneuvers with pitch errors were precision propagated to the midcourse maneuver point. At specific delay times, T_D, on these coast trajectories, minimum fuel, unspecified area abort maneuvers retargeted to the corridor centerline were performed to simulate midcourse corrections. A minimum T_{AR} constraint of 1.5 hours was assumed, so that data were generated only for burn times of 180 seconds and greater. Figure 3-3 presents midcourse delta velocity, ΔV_{MC}, versus the delay time from the fixed-attitude abort for $\Delta\beta$ = +3 degrees, while Figure 3-4 shows the same information for $\Delta\beta$ = -3 degrees. The ΔV requirements for these maneuvers are extremely low for all of the S-IVB burn times shown with each curve having a minimum value of approximately 40 feet per second. The minimum value of each curve corresponds to performing the midcourse at apogee on the postabort orbit.

Cross-plots of Figures 3-3 and 3-4 are presented in Figures 3-5 and 3-6. These plots display ΔV_{MC} as a function of T_B for midcourse maneuvers performed at delay times of 1 hour, 1.5 hours, and at apogee on the postabort trajectories.

Figures 3-1 through 3-6 all help explain the interplay between midcourse maneuver requirements and operational constraints. Figures 3-5 and 3-6 illustrate that midcourse corrections performed immediately after a 1-hour preparation time require relatively low fuel expenditures (ΔV_{MC} = 40 to 60 feet per second). The 1-hour delay time provides excellent midcourse capability for S-IVB burn times as low as 160 seconds. At this burn time, abort entry conditions are still well within the corridor even for plus or minus 3-degree pitch misalignments, although they exhibit appreciable deviations from the target line. Midcourse maneuvers for burn times between 160 seconds and the nominal TLI burn of 333.24 seconds may be readily performed at a delay time of one hour following the fixed-attitude abort maneuver. This procedure allows for a minimum preparation time of one hour and a CM/SM separation time of at least one-half hour prior to earth entry.

Midcourse maneuvers performed at a delay time of 1.5 hours require extremely high fuel expenditures for S-IVB burn times below approximately 200 seconds with $\Delta\beta = +3$ degrees. More important, the time remaining to entry is quite low, less than one-half hour below $T_B = 210$ seconds. As was mentioned previously, this region of the S-IVB burn is an extremely critical one, because entry conditions can be near the corridor boundary. It is questionable whether or not to set the midcourse delay time to 1.5 hours since corrections would not be possible for burn times less than about 210 seconds, and large entry deviations would remain uncorrected. It may be advantageous to define a split procedure with regard to delay time from abort to midcourse. The procedure would be such that for burn times (or S-IVB V_{GO}) below a certain value, the midcourse correction would be performed at $T_D = 1$ hour. Above this burn time, the maneuver would be initiated at T_D = 1.5 hours. The value of S-IVB burn time which would serve as a transition point would be that time above which it is possible to delay 1.5 hours from the abort maneuver before performing the midcourse maneuver. This procedure would permit midcourse corrections for burn times as low as 160 seconds, while retaining the advantage of allowing more preparation time for burn times with entry conditions outside the corridor boundaries which must be corrected. The disadvantage, of course, is that it is a split procedure and is not as simple as delaying a fixed time for all burn durations.

As shown in Figures 3-5 and 3-6, the procedure which exhibits the absolute minimum fuel expenditures would be to perform the midcourse correction at apogee on the postabort trajectory. This procedure, however, suffers the disadvantage of not allowing even an hour of preparation time for burn times less than about 215 seconds, while presenting the additional problem of determining when apogee is reached.

Values of the time from midcourse to entry, T_{MR}, as a function of burn time are shown in Figures 3-7 and 3-8 for $\Delta\beta$ = +3 and -3 degrees, respectively. It can be seen that T_{MR} is actually only a function of T_D on the postabort trajectory, because the fuel expenditures for the midcourse maneuver are sufficiently small so that they do not significantly alter the total trip time from abort to earth entry.

Figure 3-9 shows premidcourse and postmidcourse miss distances (nominal landing point minus perturbed landing point) as a function of the S-IVB burn time. The premidcourse miss distance is relatively large for $\Delta\beta$ = +3 degrees and exceeds 600 nautical miles for the nominal TLI burn. Postmidcourse miss distances, however, lie below 150 nautical miles for most of the correctable portion of the burn. These values do not take into account the entry ranging capabilities of the spacecraft. The present analysis was concerned only with correcting the pitch errors by retargeting for the corridor centerline and noting the associated miss distances. Future studies will examine the fuel expenditures required to drive miss distance to zero by targeting the midcourse to a specified site, namely the nominal landing point, in addition to the target line.

3.3 SUMMARY

The following observations and conclusions have been derived from this investigation of midcourse maneuver requirements:

- The ΔV requirements for midcourse maneuvers are extremely low and rarely exceed 100 feet per second.
- The desire for long midcourse maneuver preparation times and the relatively short postabort flight times encountered may result in the definition of a split procedure for midcourse corrections.
- The flight time associated with a midcourse corrected trajectory is essentially equal to that for the same trajectory without a midcourse correction.

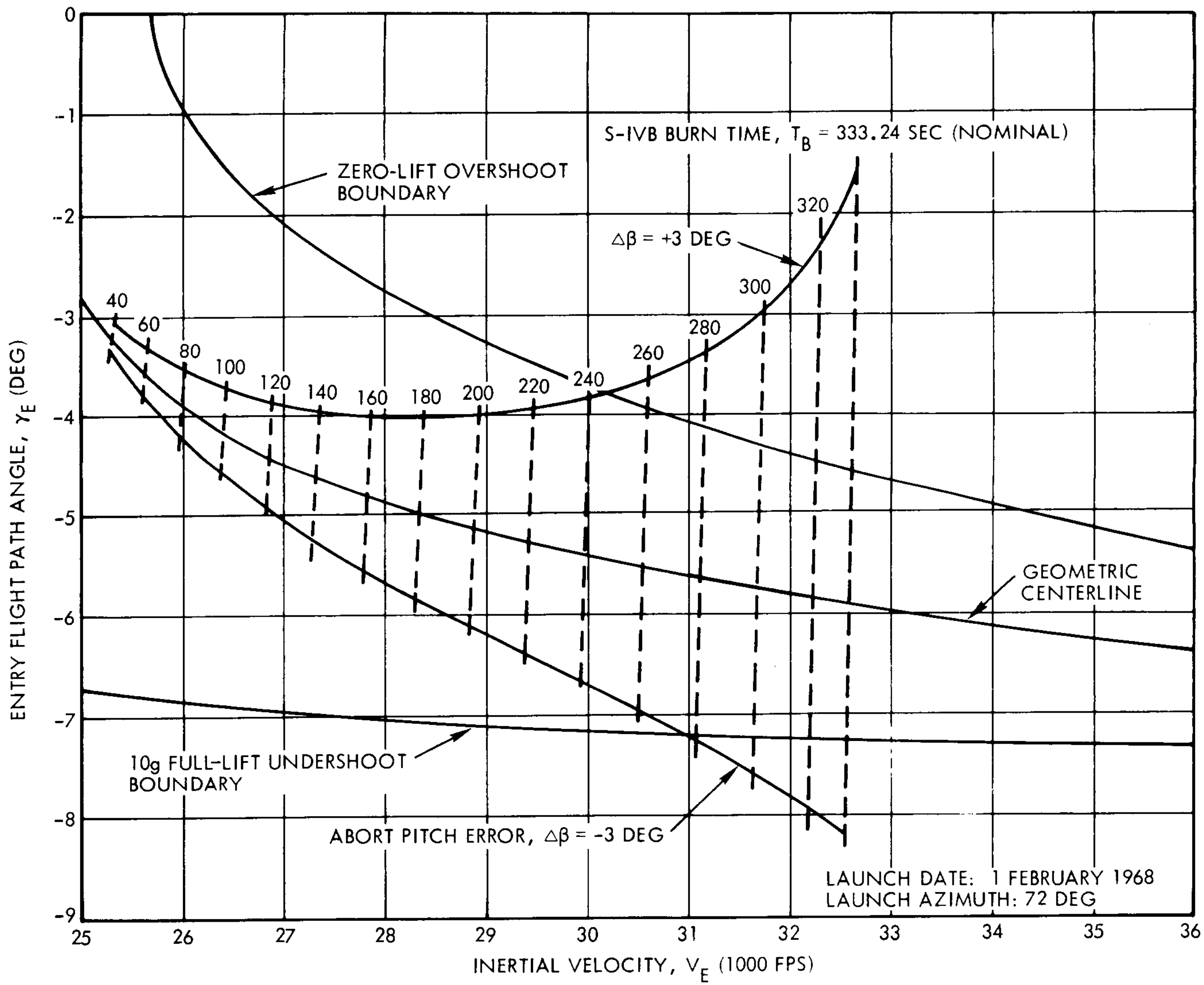

Figure 3-1. Entry Conditions for Fixed-attitude Abort Maneuvers

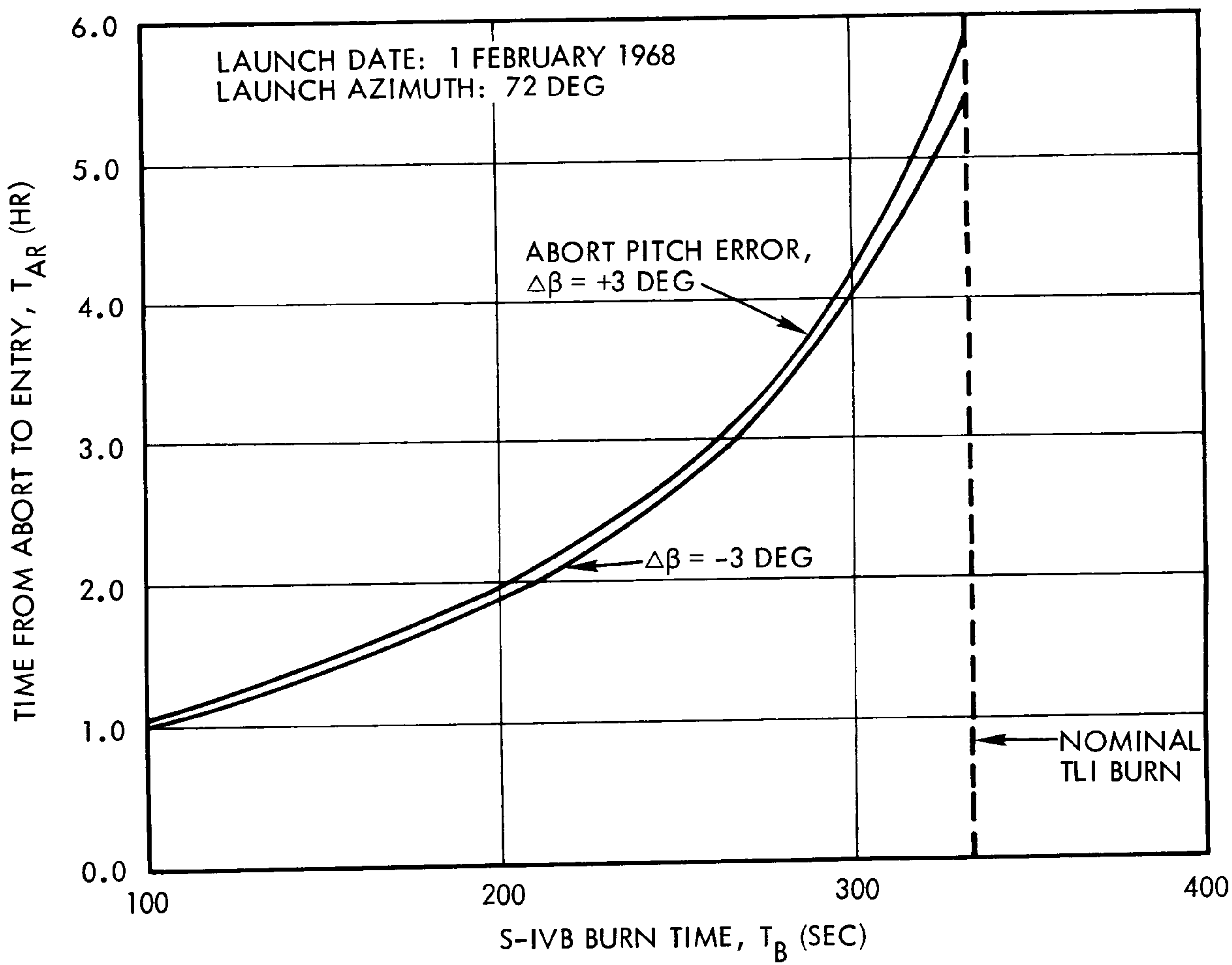

Figure 3-2. Time from Abort to Entry as a Function of S-IVB Burn Time for Fixed-attitude Abort Maneuvers

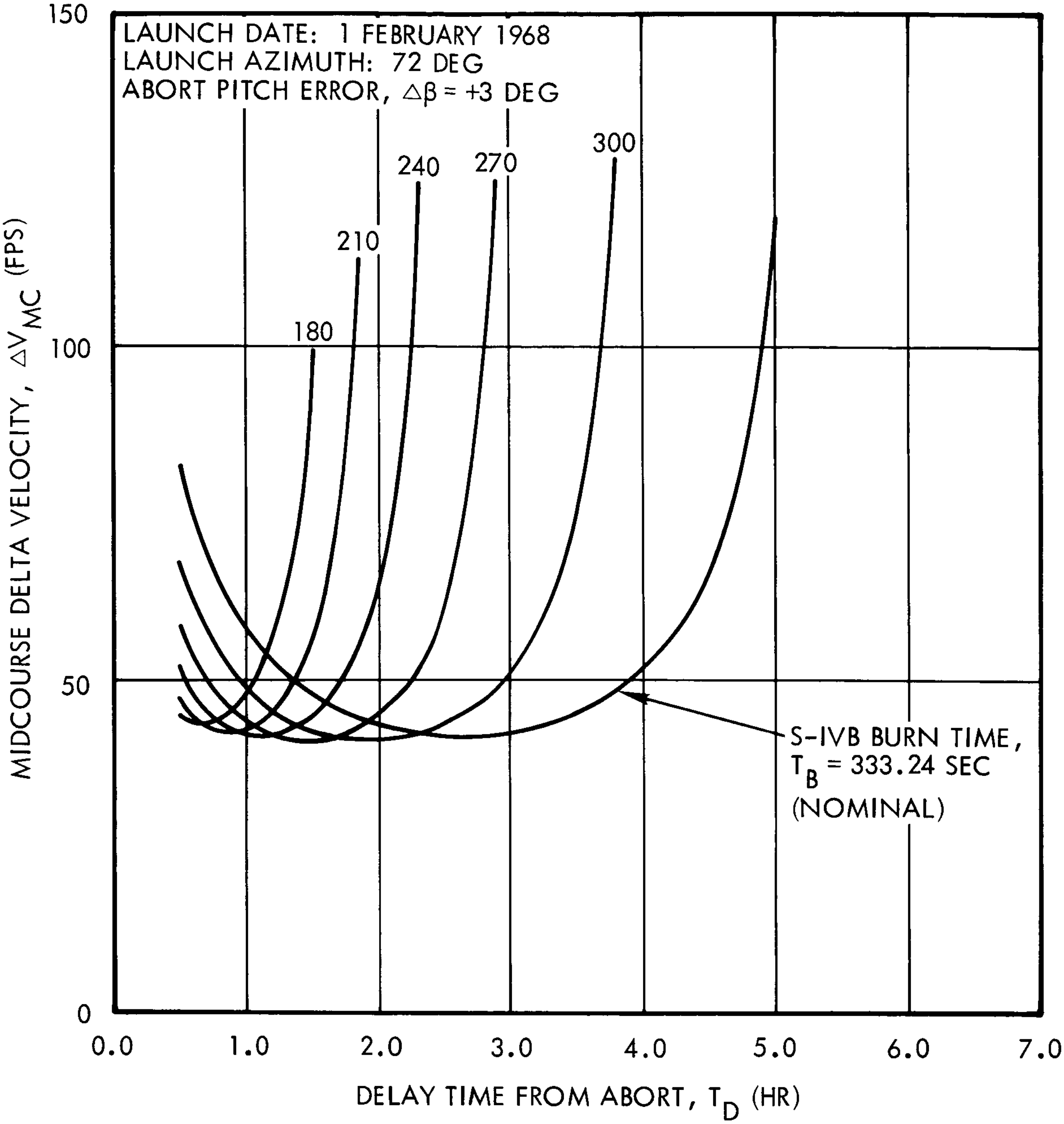

Figure 3-3. Midcourse Delta Velocity as a Function of Delay Time from Abort ($\Delta\beta$ = +3 deg)

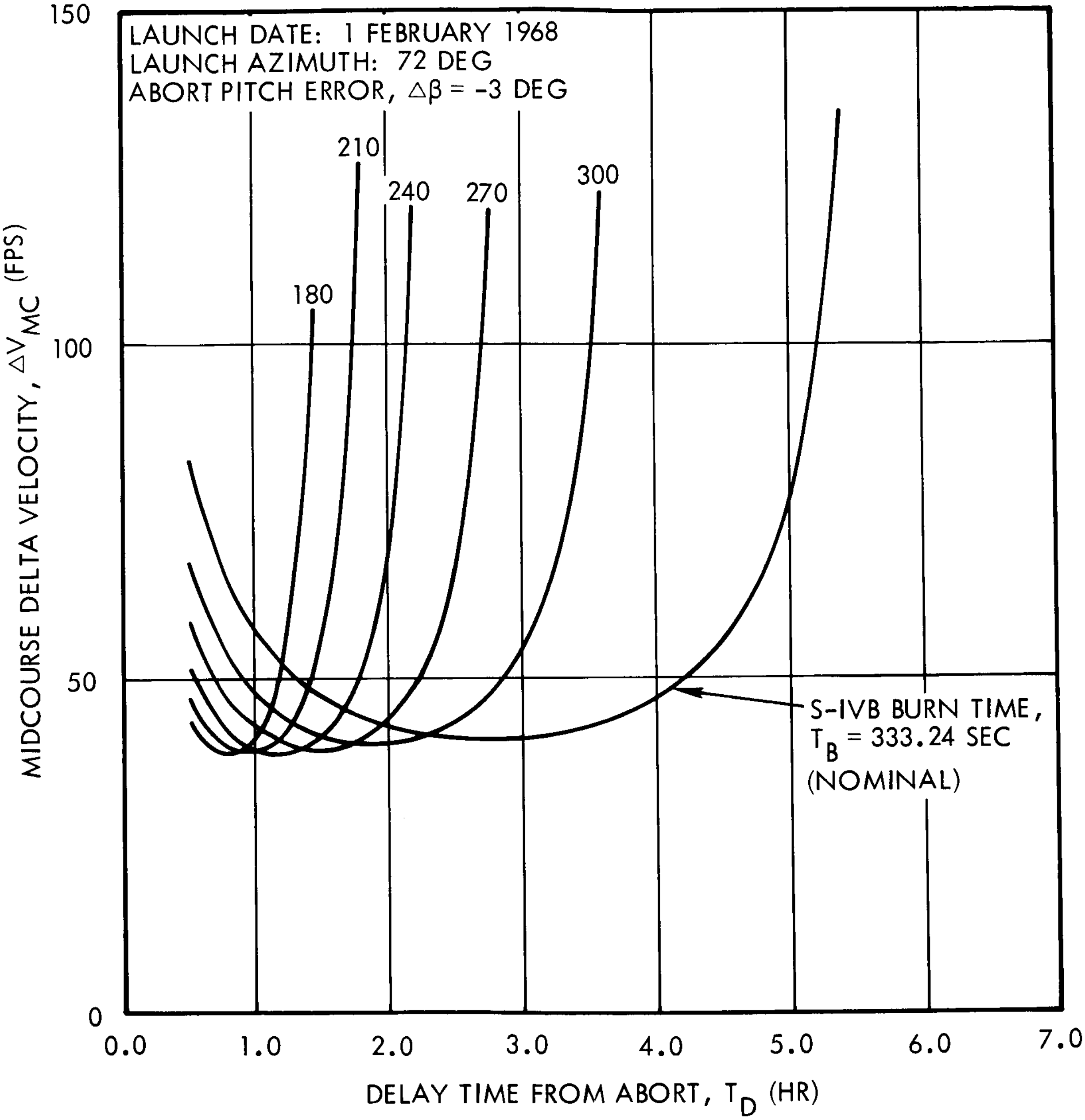

Figure 3-4. Midcourse Delta Velocity as a Function of Delay Time from Abort ($\Delta\beta$ = -3 deg)

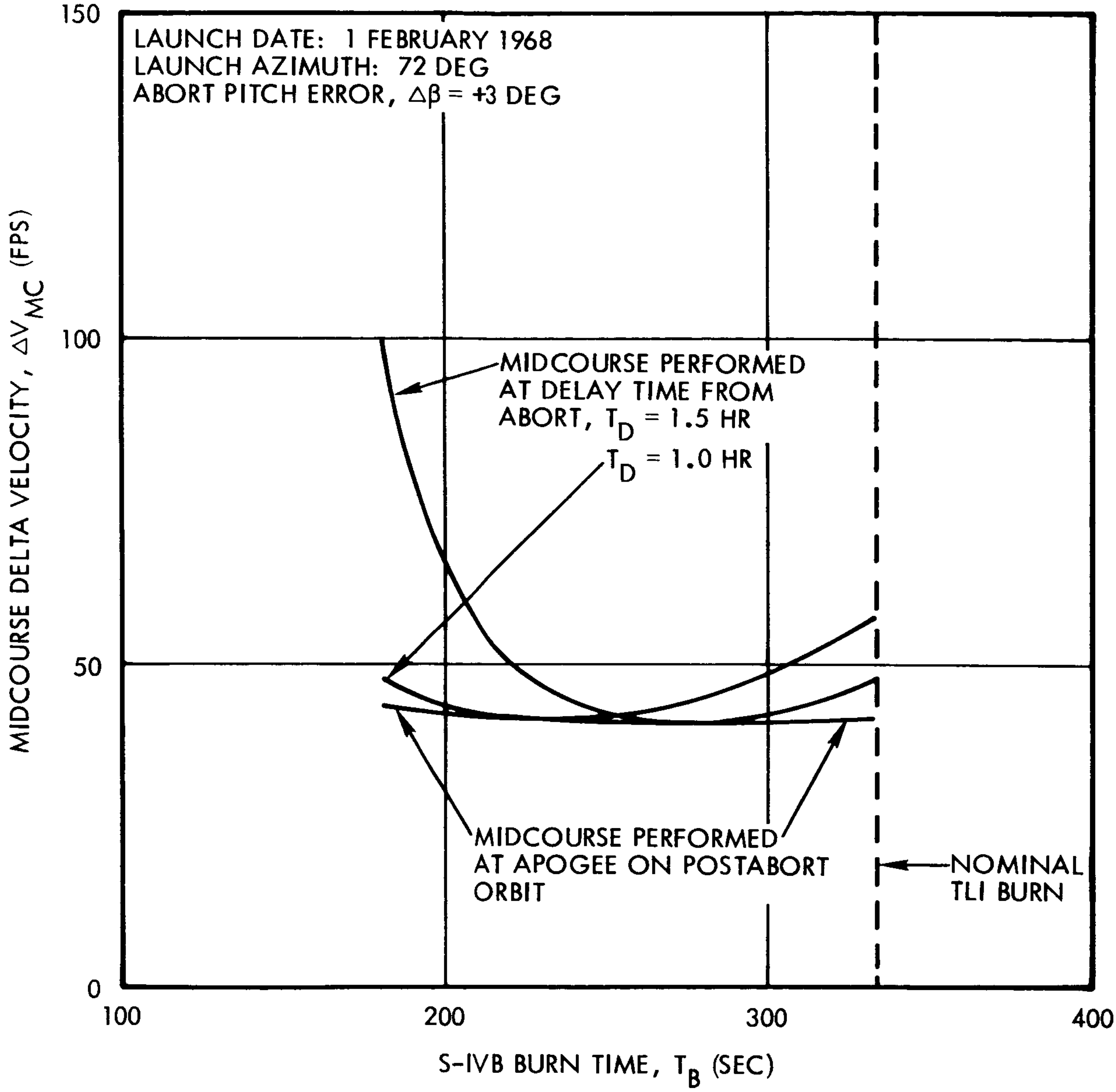

Figure 3-5. Midcourse Delta Velocity as a Function of S-IVB Burn Time ($\Delta\beta$ = +3 deg)

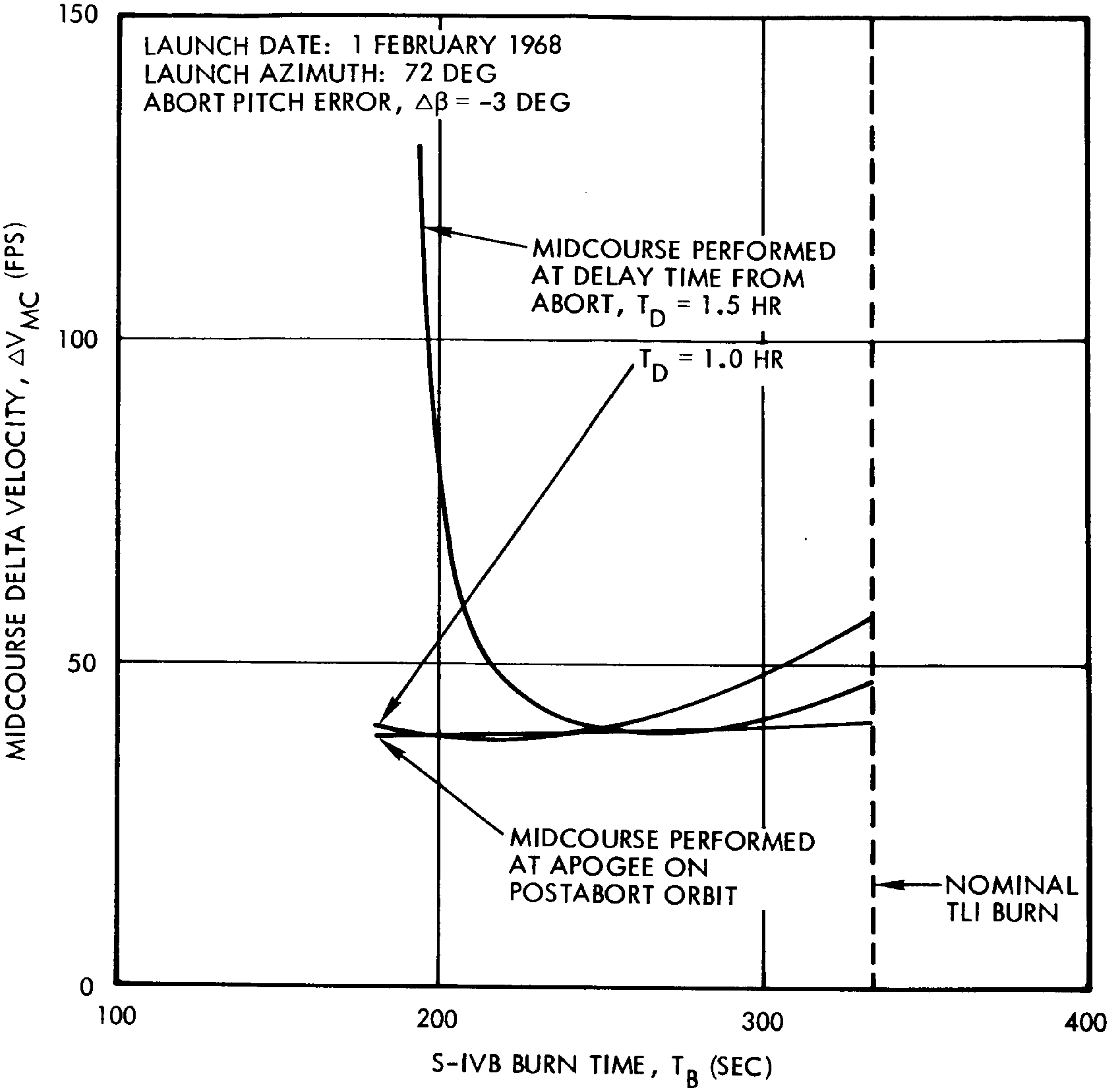

Figure 3-6. Midcourse Delta Velocity as a Function of S-IVB Burn Time ($\Delta\beta$ = -3 deg)

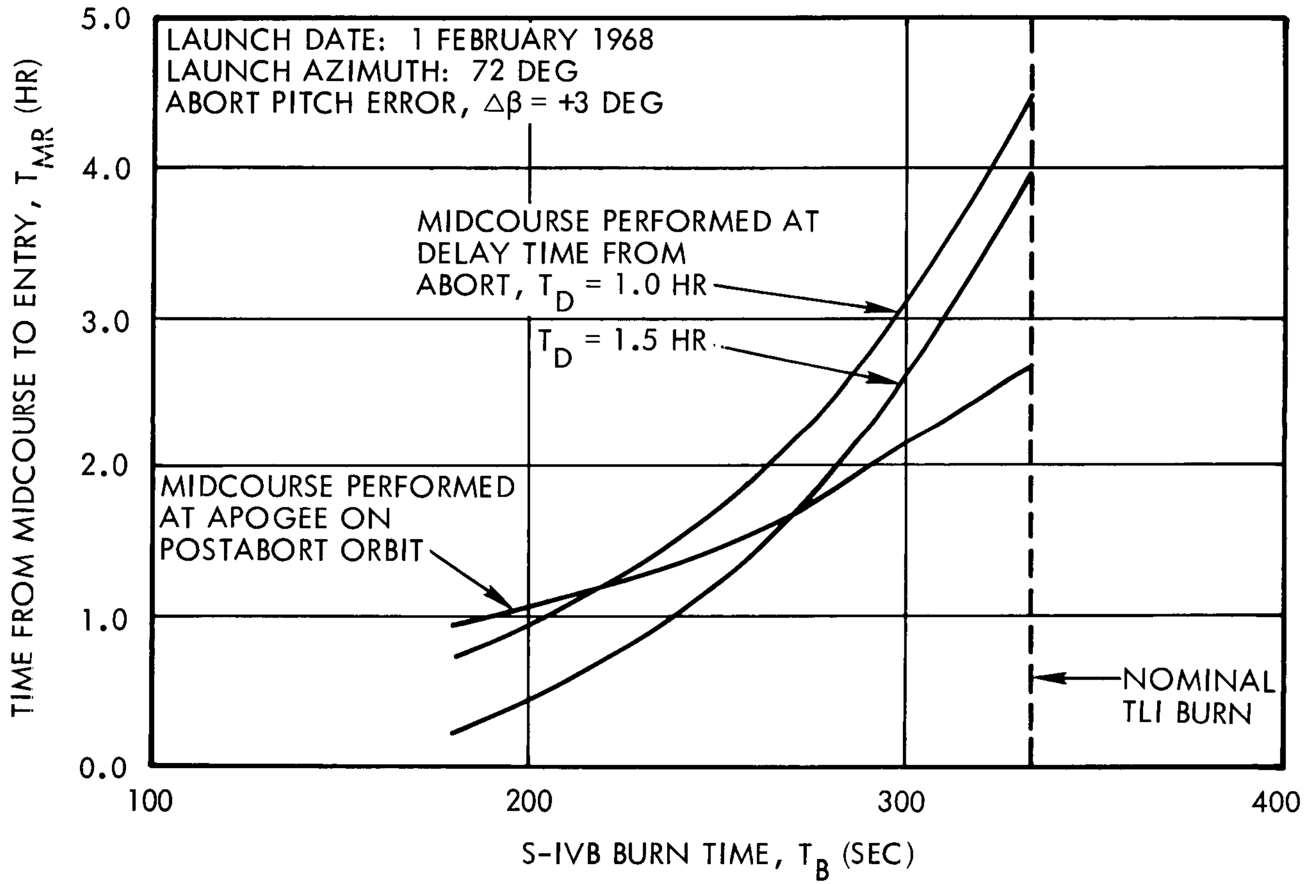

Figure 3-7. Time from Midcourse to Entry as a Function of S-IVB Burn Time ($\Delta\beta$ = +3 deg)

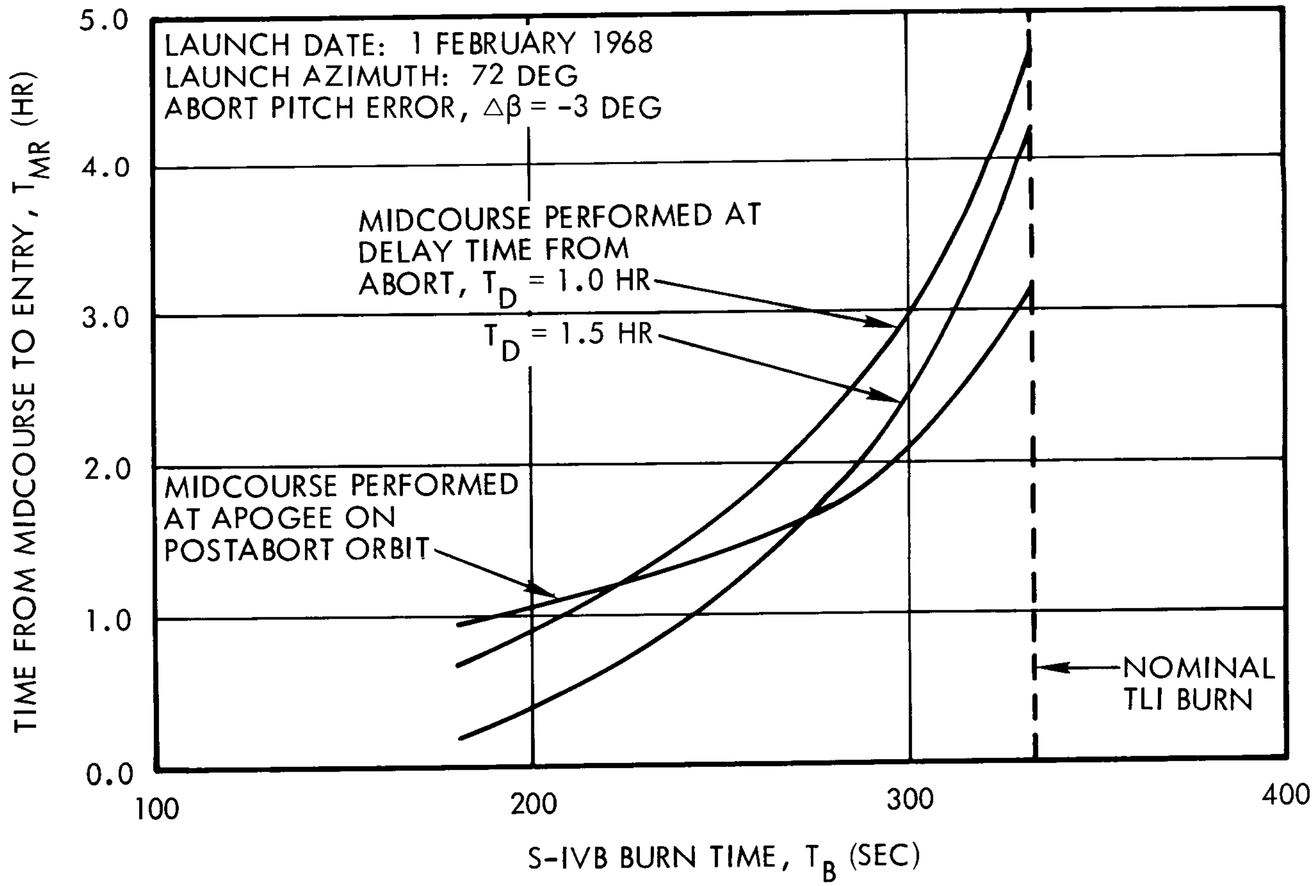

Figure 3-8. Time from Midcourse to Entry as a Function of S-IVB Burn Time ($\Delta\beta = -3$ deg)

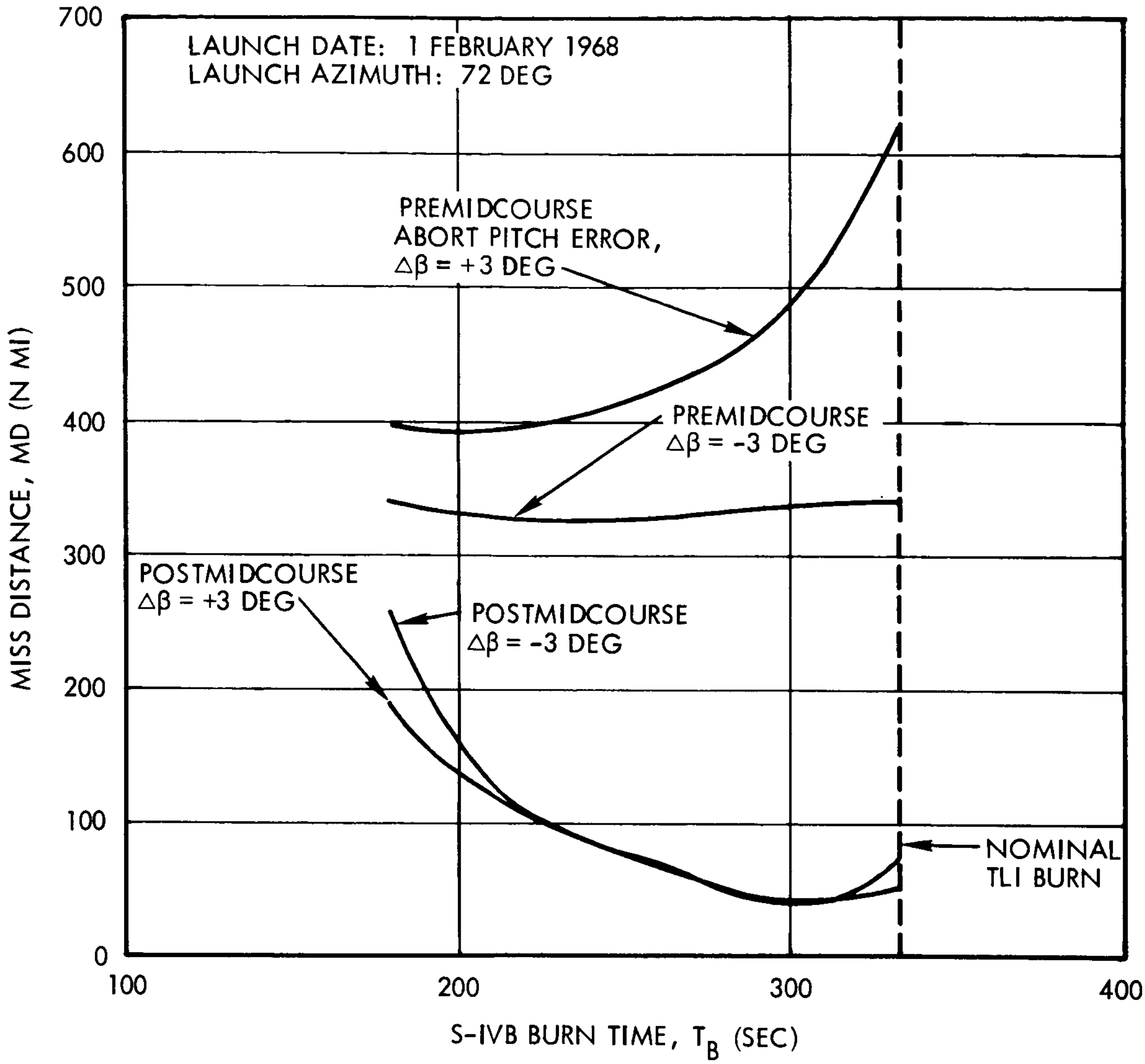

Figure 3-9. Premidcourse and Postmidcourse Miss Distance as a Function of S-IVB Burn Time

4. MSFN TRACKING

4.1 GENERAL

An analysis was conducted to determine the amount of tracking coverage MSFN tracking stations can afford the fixed-attitude abort maneuver and any midcourse corrections which may become necessary. Both preabort and postabort tracking data were considered, even though it is not absolutely necessary that tracking coverage be available for either the abort maneuver or the midcourse correction. The fixed-attitude abort procedure discussed in Section 2 is designed so that no ground support of any kind is required, while the midcourse maneuver procedure could, in the absence of tracking and communications, be carried out with onboard systems.

4.2 DISCUSSION

Preabort and postabort tracking data were generated for the six TLI burns discussed in Section 2.2. Premature S-IVB burnout state vectors were propagated forward to the abort point, and postabort state vectors resulting from the fixed-attitude aborts were propagated to earth entry to obtain the data. The tracking model employed assumes conic propagation of the state vectors, with the tracking sites specified with respect to the Fischer ellipsoid. A minimum elevation angle of five degrees was employed in the analysis and no keyhole constraints were considered. Data were generated for land-based stations only; the locations and capabilities of these fourteen stations are shown in Table 4-1. The fixed-attitude abort maneuvers used in the analysis were assumed to be nominal, with no perturbed trajectories being considered.

Tracking summaries for two February 1968 launch dates and three launch azimuths are presented in Figures 4-1 through 4-6. These summaries show both preabort and postabort tracking capabilities for each TLI burn. The burn time versus ground elapsed time from S-IVB ignition arrangement of the plot provides a convenient method of locating and determining tracking coverage for specific events, such as the abort maneuver and midcourse corrections. The ignition times associated with the fixed-attitude, fixed-delay time aborts are shown on each summary as the nearly vertical line toward the left of each plot. The cross-hatched region or regions on each graph represent intervals in which both tracking and UHF command capabilities exist simultaneously. Intervals in which the spacecraft is tracked only by a station with no UHF command capability are represented by shading on the summaries. Cross-hatched or shaded regions represent intervals of time in which the spacecraft is being tracked by at least one, and possibly more than one, station at those times. In some cases the capability for as many as ten stations to afford tracking support exists simultaneously.

Interpretation of the tracking summaries is fairly easy, and a sample case will illustrate their use. Suppose, for example, that a shutdown of the S-IVB stage occurs at 200 seconds into the burn occurring on 1 February with a launch azimuth of 72 degrees (Figure 4-1). Inspection of Figure 4-1 at T_B = 200 seconds shows that tracking coverage begins approximately five minutes before the abort maneuver is initiated. It may be mentioned again that the fixed-attitude abort procedure does not require tracking or any type of ground support; therefore, the presence or absence of preabort tracking is of little concern at this time. It is desirable, however, to have tracking support for any midcourse corrections which may be required. Assuming that the midcourse correction is to be performed at a delay time of one hour after the abort maneuver, the summary shows that continuous tracking exists for the 1-hour interval between the abort and midcourse. After the midcourse maneuver is performed there are 48 minutes of additional tracking support, although command capabilities are lost ten minutes prior to loss of tracking. Entry occurs 66 minutes after the midcourse maneuver.

It is evident from the six summaries that tracking support for midcourse maneuvers is excellent. It was pointed out in Section 4 that midcourses cannot be performed for premature S-IVB cutoffs prior to approximately 160 seconds into the TLI burn. Abort execution errors have no effect on the coverage for midcourse maneuvers. Although postmidcourse trajectories differ slightly from premidcourse trajectories, the difference has a negligible effect on tracking times.

4.3 SUMMARY

The following observations and conclusions have been derived from this investigation of MSFN tracking:

- Tracking coverage for the minimum fuel midcourse maneuver is excellent with continuous tracking existing for the burn time regions where pointing errors might necessitate a midcourse.
- For the cases studied, tracking support rarely exists during entry.
- Command capability is often lost prior to the loss of tracking by the stations.

Table 4-1. MSFN Tracking Stations

Call Letters	Station Name (USB)	Geodetic Latitude (deg)	Longitude (deg)	Altitude Above Fischer Ellipsoid (ft)	UHF Command
HAW	Hawaii	22. 12807249	-159. 66722638	3730. 019700	Yes
GDS	Goldstone	35. 34169500	-116. 87328830	3168. 440000	No
GYM	Guaymas	27. 96320610	-110. 72084916	63. 709468	No
TEX	Corpus Christi	27. 65361111	-97. 37833333	0. 000000	Yes
MLA	Merritt Island	28. 50827222	-80. 52674611	40. 879983	Yes
GBI	Grand Bahama	26. 65416666	-78. 15277778	0. 000000	Yes
BDA	Bermuda	32. 35128694	-64. 65818111	68. 899990	Yes
ANT	Antigua	17. 01944444	-61. 75000000	0. 000000	Yes
ASC	Ascension	-7. 95523416	-14. 32757889	1841. 210000	No
MAD	Madrid	40. 45535833	-4. 16739555	2707. 510000	No
CRO	Carnarvon	-24. 90756278	113. 72424722	188. 319960	Yes
GWM	Guam	13. 30823555	144. 73441361	420. 279990	No
CNB	Canberra	-35. 59722222	148. 97916666	0. 000000	No
CYI	Grand Canary	27. 74027700	-15. 60416600	0. 000000	Yes

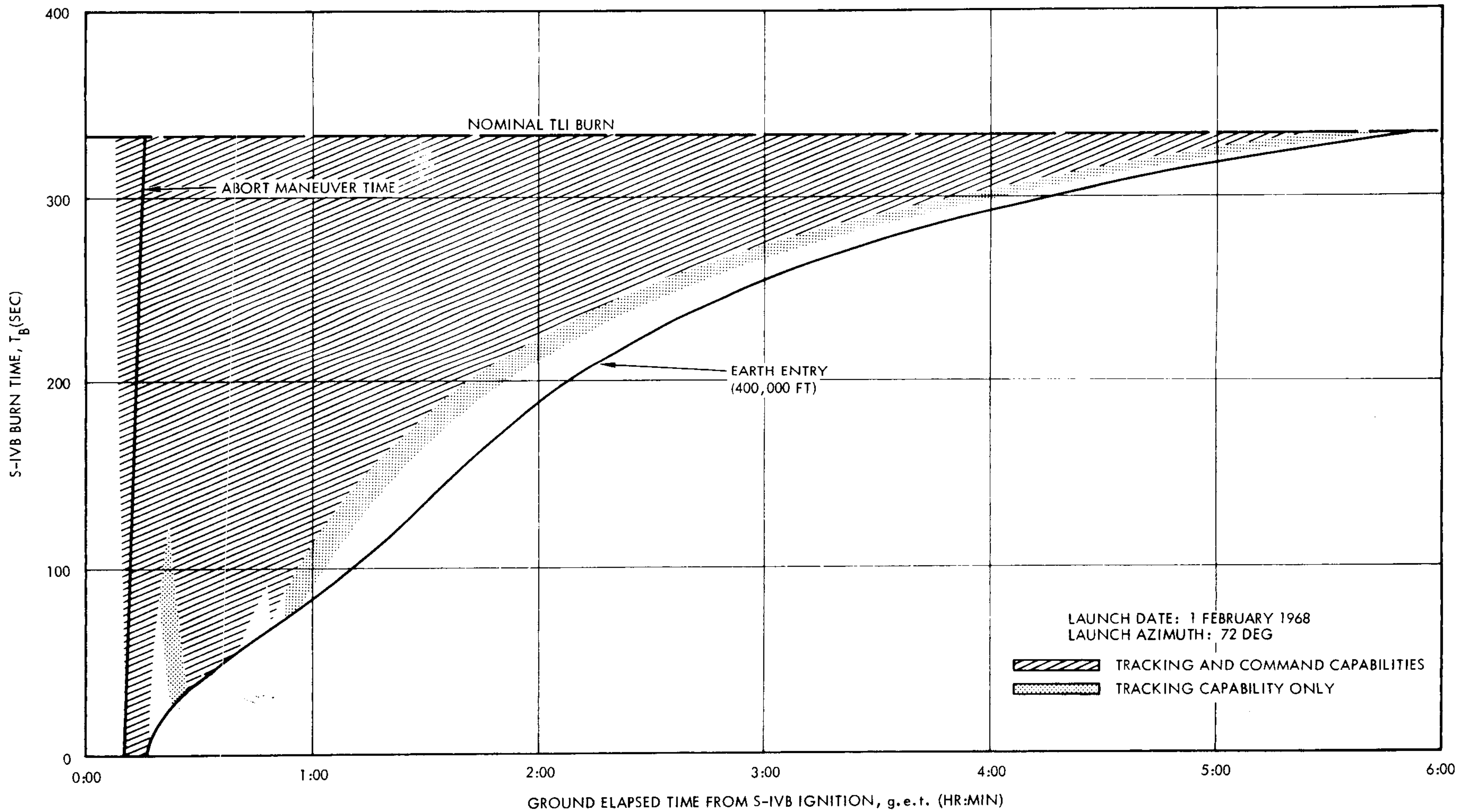

Figure 4-1. Tracking Summary for 1 February; Launch Azimuth of 72 Degrees

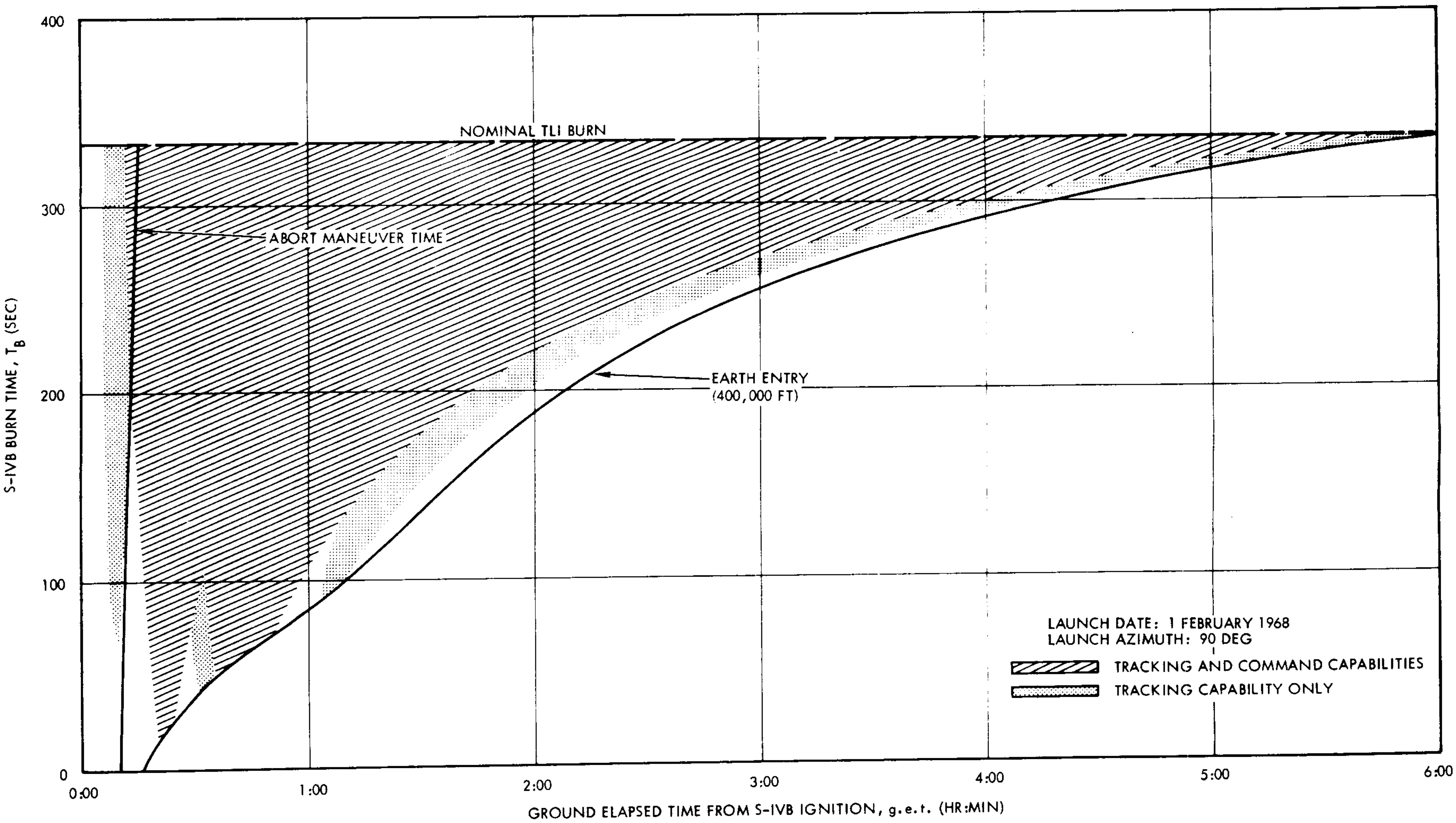

Figure 4-2. Tracking Summary for 1 February; Launch Azimuth of 90 Degrees

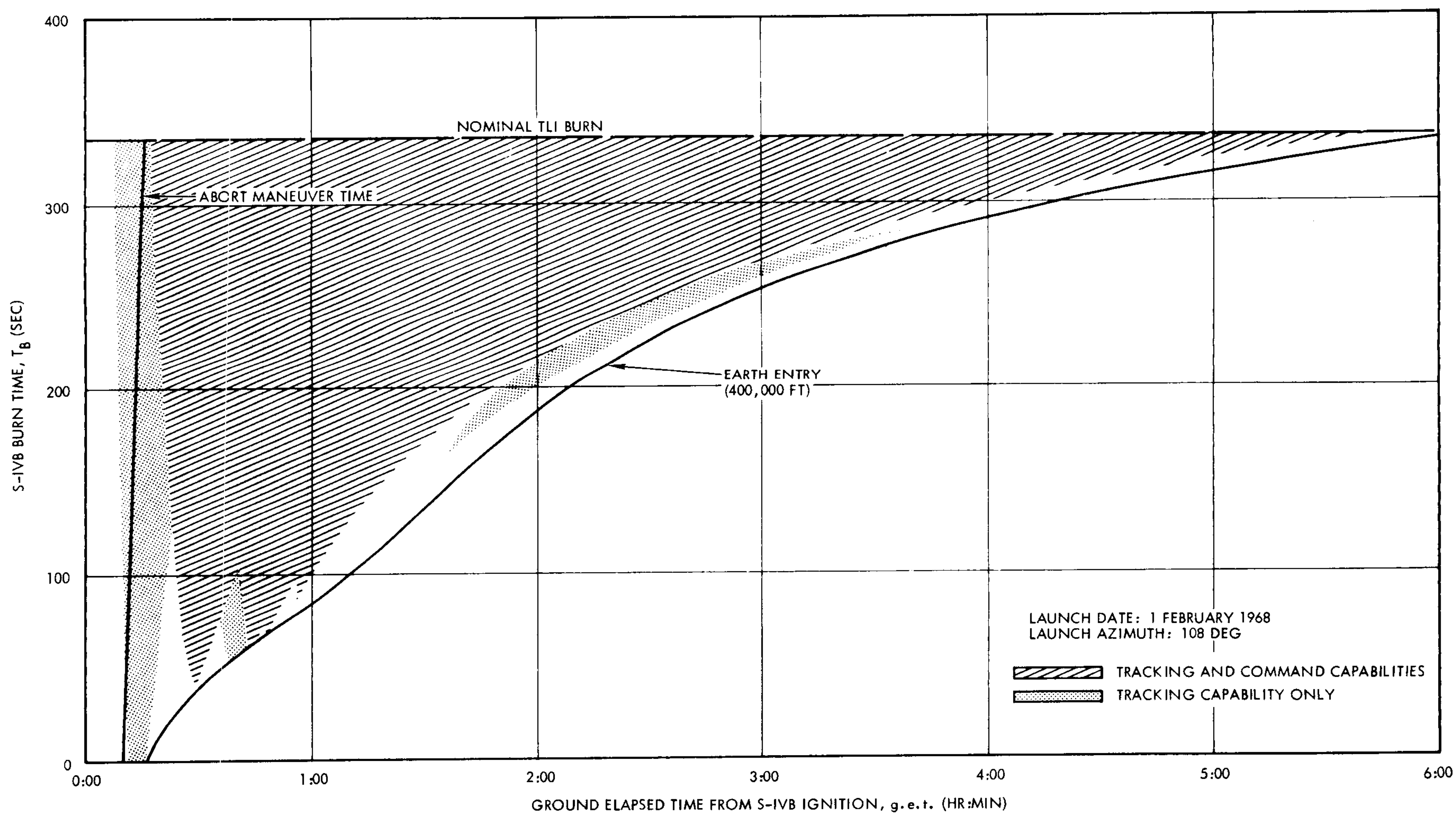

Figure 4-3. Tracking Summary for 1 February; Launch Azimuth of 108 Degrees

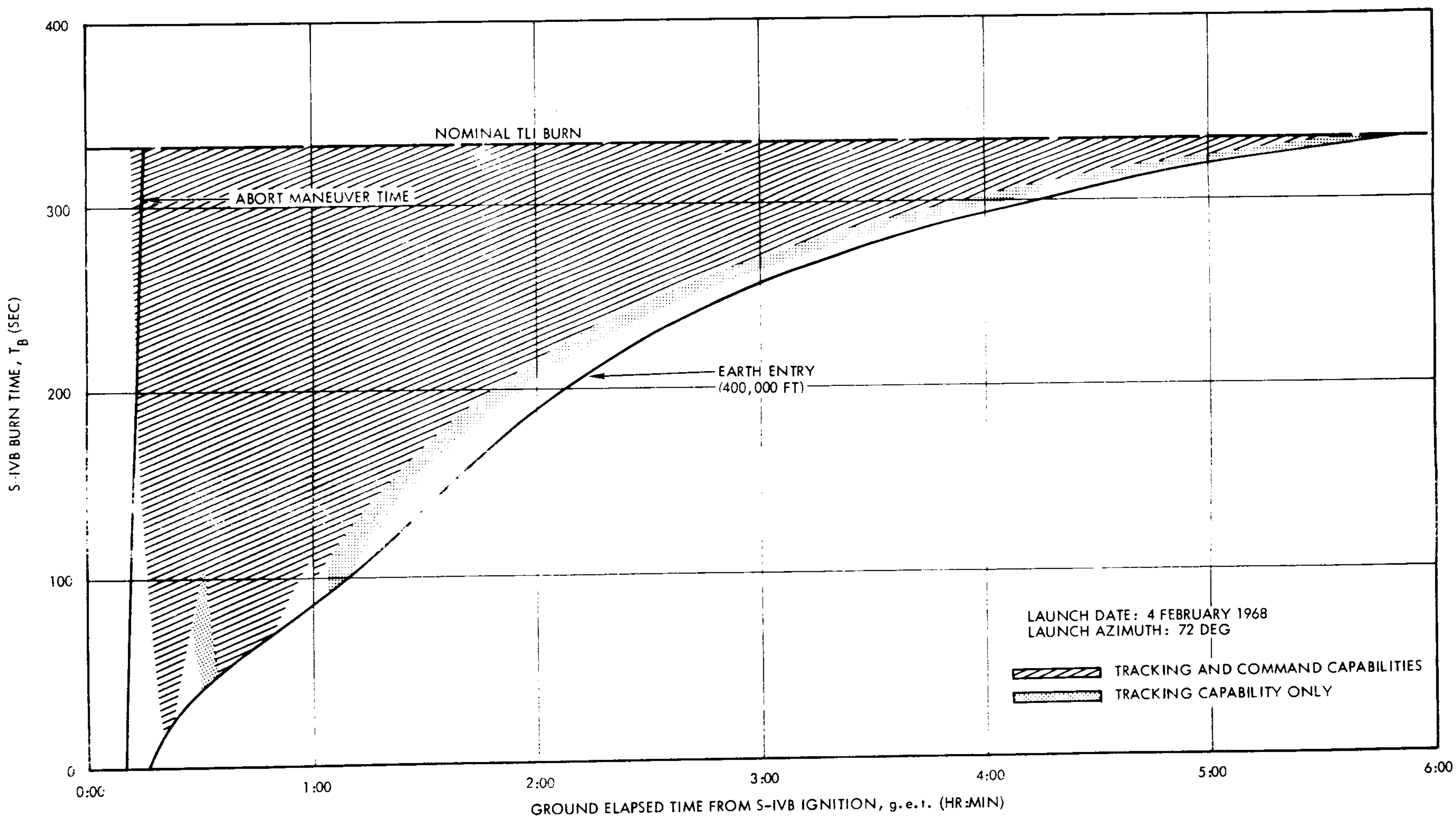

Figure 4-4. Tracking Summary for 4 February; Launch Azimuth of 72 Degrees

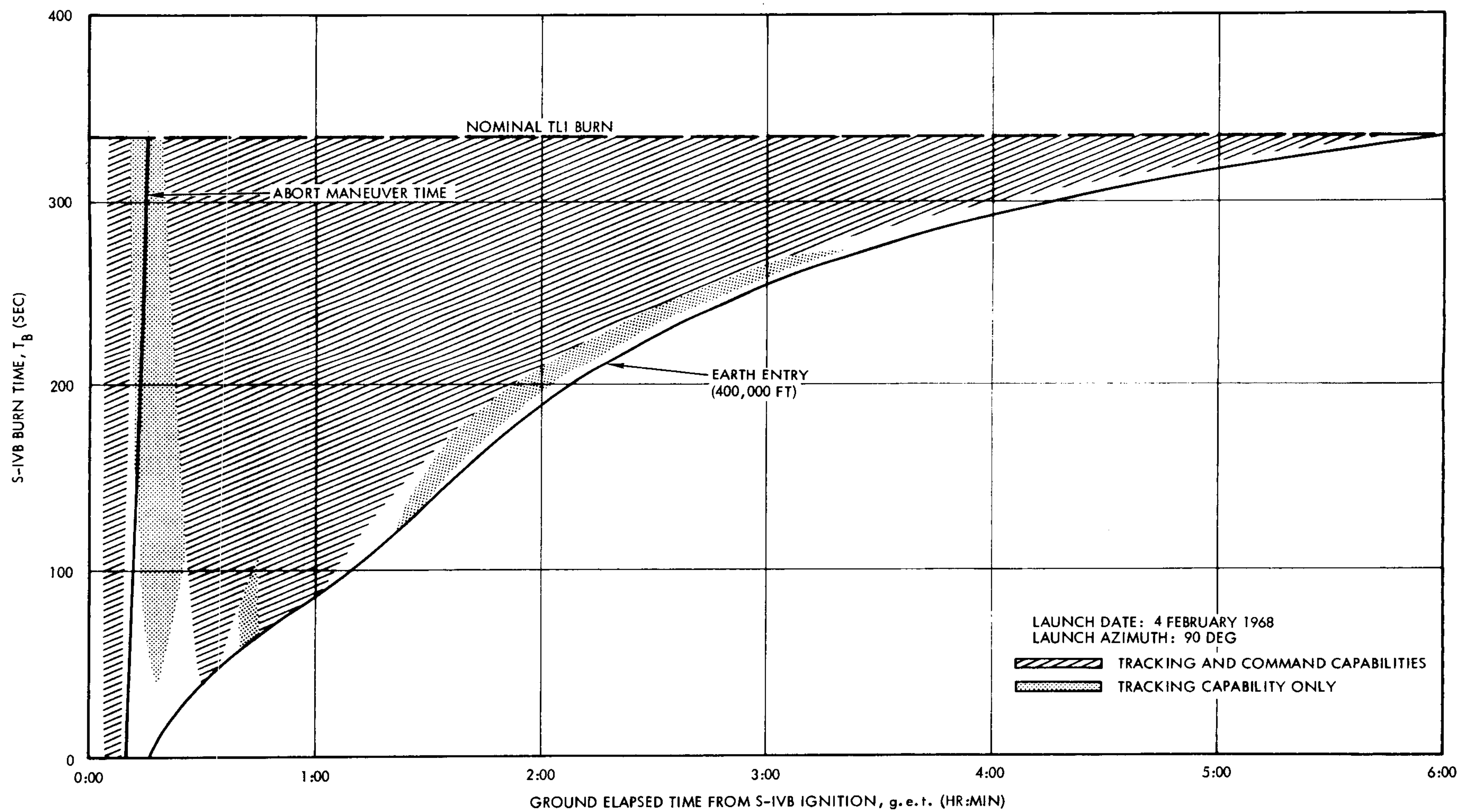

Figure 4-5. Tracking Summary for 4 February; Launch Azimuth of 90 Degrees

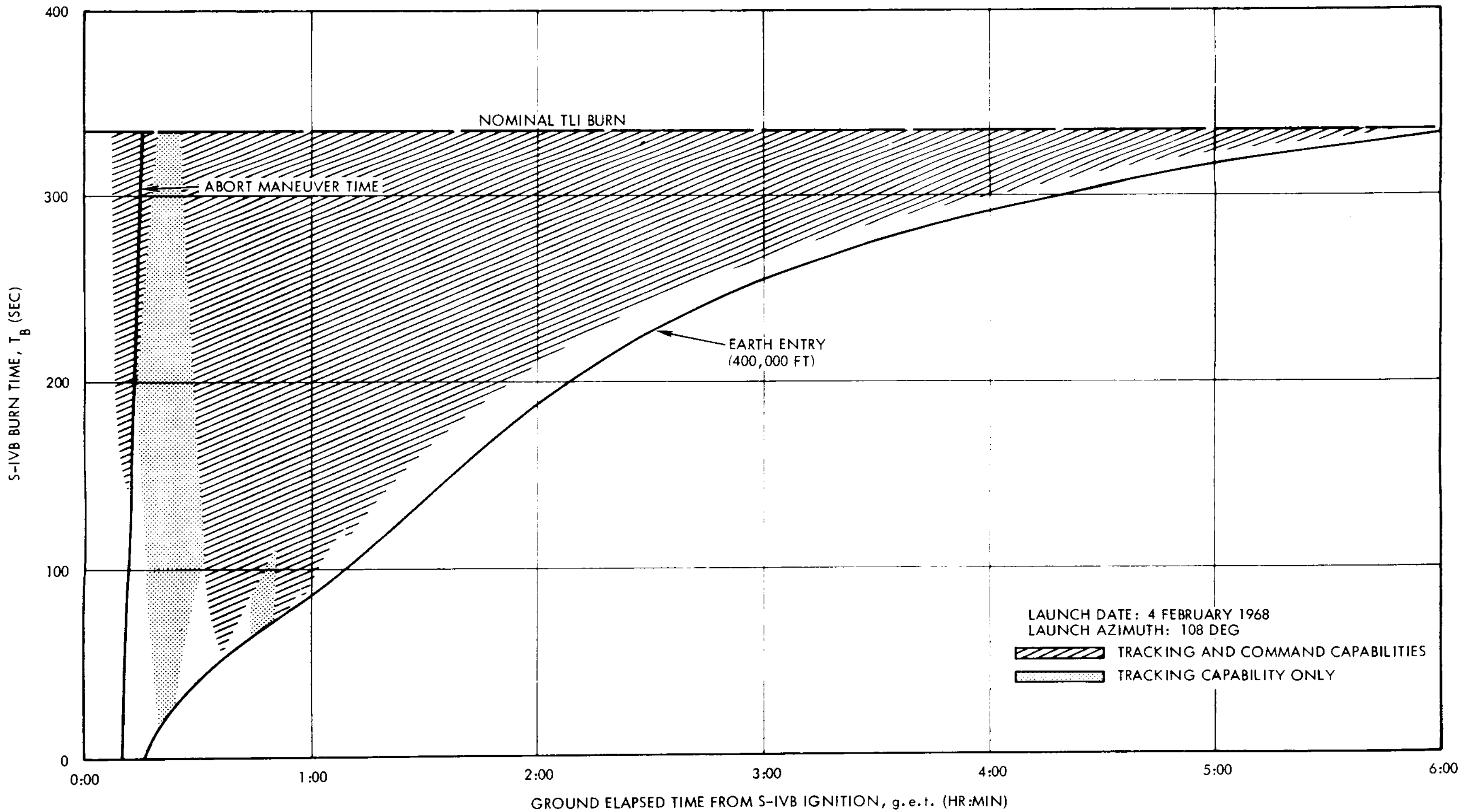

Figure 4-6. Tracking Summary for 4 February; Launch Azimuth of 108 Degrees

5. CONCLUSIONS

The following list of conclusions summarizes the major points determined in Sections 2, 3, and 4.

For the fixed-attitude abort maneuver:

- A simple, readily performed procedure can be adopted for the fixed-attitude (heads up) type of abort, with the horizon reference angle and the time of abort fixed at +5 degrees with respect to the far horizon and 10 minutes after S-IVB shutdown, respectively.

- For all launch dates and azimuths considered, less than half of the available SPS ΔV is required by the abort maneuver.

- The return flight times for the launch dates and azimuths considered are all less than six hours.

- It appears feasible to use a single crew chart (i.e., a plot of ΔV as a function of V_{GO}) for each launch date, irregardless of the launch azimuths, in order to obtain the abort ΔV. In fact, the difference between the two daily crew charts is so small ($\lesssim$ 20 feet per second) that it is entirely practical to use either one as a crew chart for all launch dates and azimuths.

- The landing point traces show relatively few land touchdowns (< 10 percent) for the two launch dates having launch azimuths of 72 degrees. For all other launch azimuths, the frequency of land touchdowns is much higher, between 20 and 58 percent.

- Landings in darkness occur approximately 85 percent of the time for the possible landing points on 1 February, for all launch azimuths considered. On 4 February the percentage of landings in darkness decreases by more than a factor of two, to 38 percent, again for all launch azimuths considered.

For the midcourse correction analysis:

- The ΔV requirements for midcourse maneuvers are extremely low and rarely exceed 100 feet per second.

- The desire for long midcourse maneuver preparation times and the relatively short postabort flight times encountered may result in the definition of a split procedure for midcourse corrections.

For the tracking study:

- Tracking coverage for the minimum fuel midcourse maneuver is excellent with continuous tracking existing for the burn time regions where pointing errors might necessitate a midcourse maneuver.

- For the cases studied, tracking support rarely exists during entry.

- Command capability is often lost prior to the loss of tracking by the stations.

APPENDIX

FIXED-ATTITUDE MIDCOURSE MANEUVERS

1. INTRODUCTION

Original definition of the midcourse maneuver analysis as described in Reference 9 called for the maneuver to be performed at a fixed attitude relative to the earth's horizon. A thrust angle, ψ, of 31.7 degrees, heads down attitude was to be employed (definitions of the terms "ψ" and "heads down" were given in Section 2). The choice of the horizon to be used for attitude alignment would be made by examining perigee conditions following the abort maneuver. If the perigee altitude was found to be too low, a thrust angle of +31.7 degrees relative to the near horizon would determine the midcourse attitude; while if perigee was too high, $\psi = -31.7$ degrees relative to the far horizon would be used.

In a recent meeting of the AAWG (Reference 10), it was decided that a minimum fuel, unspecified area midcourse procedure, rather than a fixed-attitude procedure, would be used. This decision was made because it seemed questionable whether the flight crew would be able to zero yaw errors using relative motion of terrestrial landmarks at the relatively high altitudes encountered. The Flight Analysis Branch is investigating this area at the present time. The results of the fixed-attitude midcourse maneuver analysis, however, will be presented here.

2. DISCUSSION

Data for the fixed-attitude SPS abort maneuver with pitch errors of plus or minus 3 degrees were generated in the same manner as that described in Section 3 (T_D = 10 minutes, heads up, ψ = 5 degrees). The only difference between the midcourse analysis discussed here and that described in Section 3 lies in the midcourse maneuver itself. For purposes of this analysis the midcourse was performed at a fixed-attitude relative to one of the earth's horizon. All data for this study were generated using the TLI burn occurring on 1 February 1968 with a launch azimuth of 72 degrees.

Postabort data for the fixed-attitude abort were examined to determine whether the induced pitch errors caused postabort perigee to be either high or low when compared with the perigee altitude following a nominal abort maneuver (no pitch errors). It was found that, for the trajectories and abort times studied, positive pitch errors typically resulted in perigee-high conditions while the opposite was true of negative pitch errors.

Postabort state vectors were again propagated from the abort point to entry. Horizon reference aborts, to simulate midcourse maneuvers, were performed on the coast trajectories with the maneuver attitude being a function of perigee conditions. The attitude for perigee-high was heads down, ψ = -31.7 degrees; and for perigee-low, heads down, ψ = +31.7 degrees. These data were generated only for S-IVB burn times of 180 seconds and greater due to the flight time considerations presented in Section 3.

Figures A-1 and A-2 present the midcourse delta velocity, ΔV_{MC}, as a function of delay time from the abort maneuver for $\Delta\beta$ = +3 degrees and $\Delta\beta$ = -3 degrees, respectively. The curves reach minimums at delay times corresponding to postabort apogee positions. Cross-plots of these two figures showing ΔV_{MC} as a function of S-IVB burn time, T_B, for midcourse maneuvers performed at T_D = 1 hour, T_D = 2 hours, and at postabort apogee are presented in Figures A-3, A-4, and A-5, respectively. Since the fixed-attitude midcourse maneuver closely approximates a minimum fuel, unspecified area maneuver, the generalizations and conclusions presented in Section 3 apply to this study.

Times from midcourse to entry as functions of S-IVB burn time are shown in Figures A-6 and A-7. Again, the postmidcourse trajectories so closely resemble the postabort trajectories without midcourses, that there is no appreciable difference in total trip time from abort to entry between midcoursed and non-midcoursed fixed-attitude abort maneuvers.

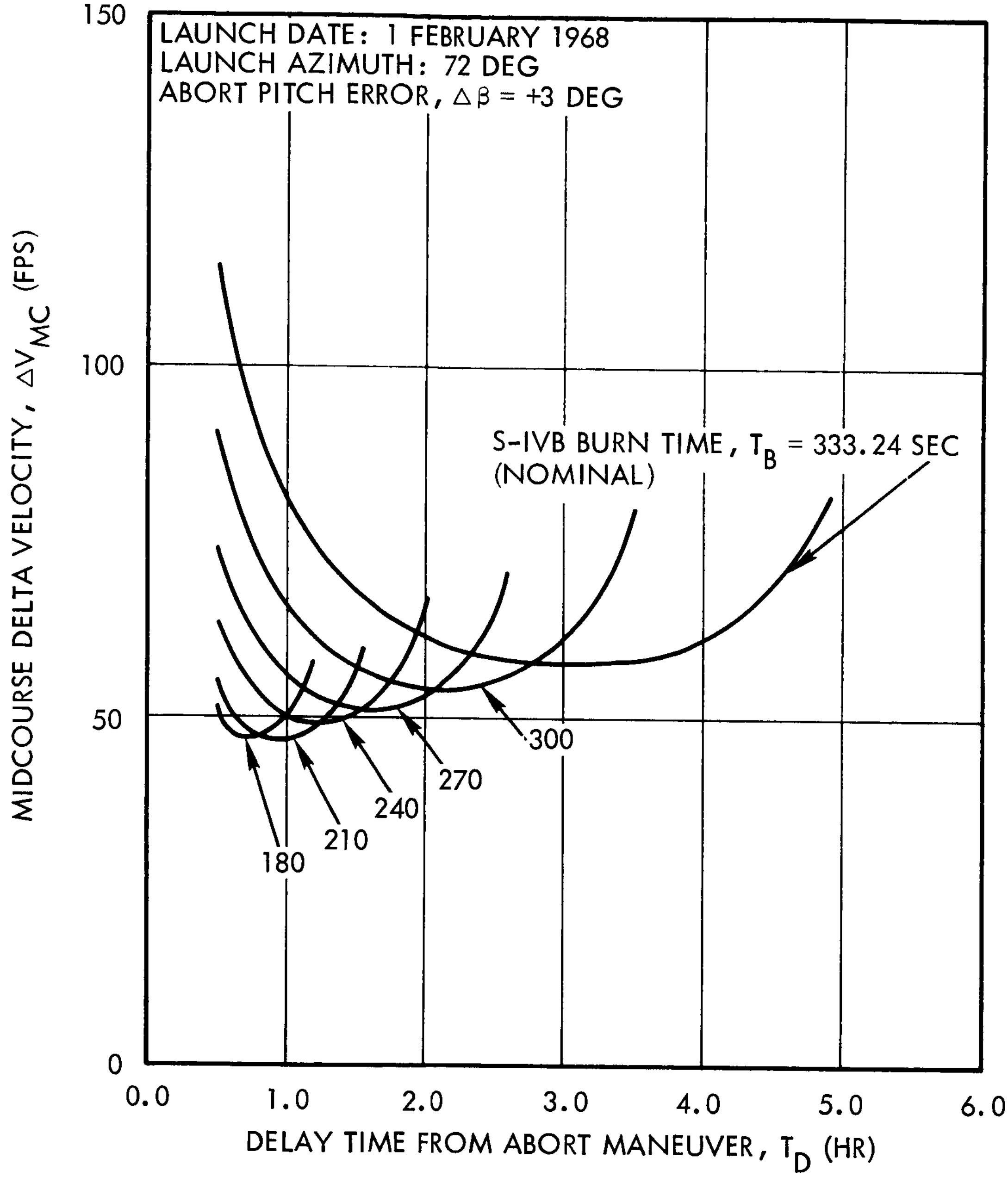

Figure A-1. Midcourse Delta Velocity as a Function of Delay Time from Abort ($\Delta\beta$ = + 3 deg)

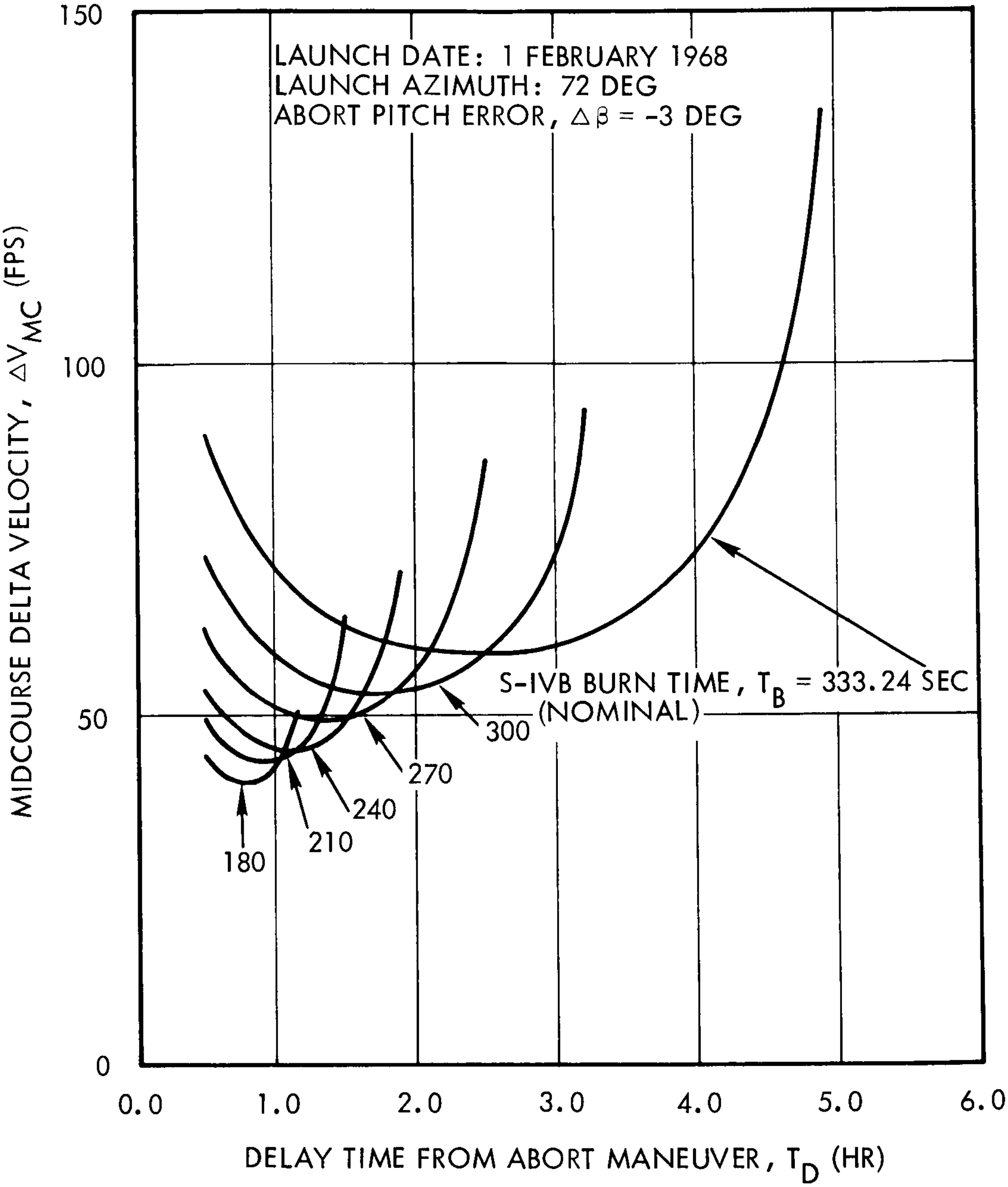

Figure A-2. Midcourse Delta Velocity as a Function of Delay Time from Abort ($\Delta\beta$ = -3 deg)

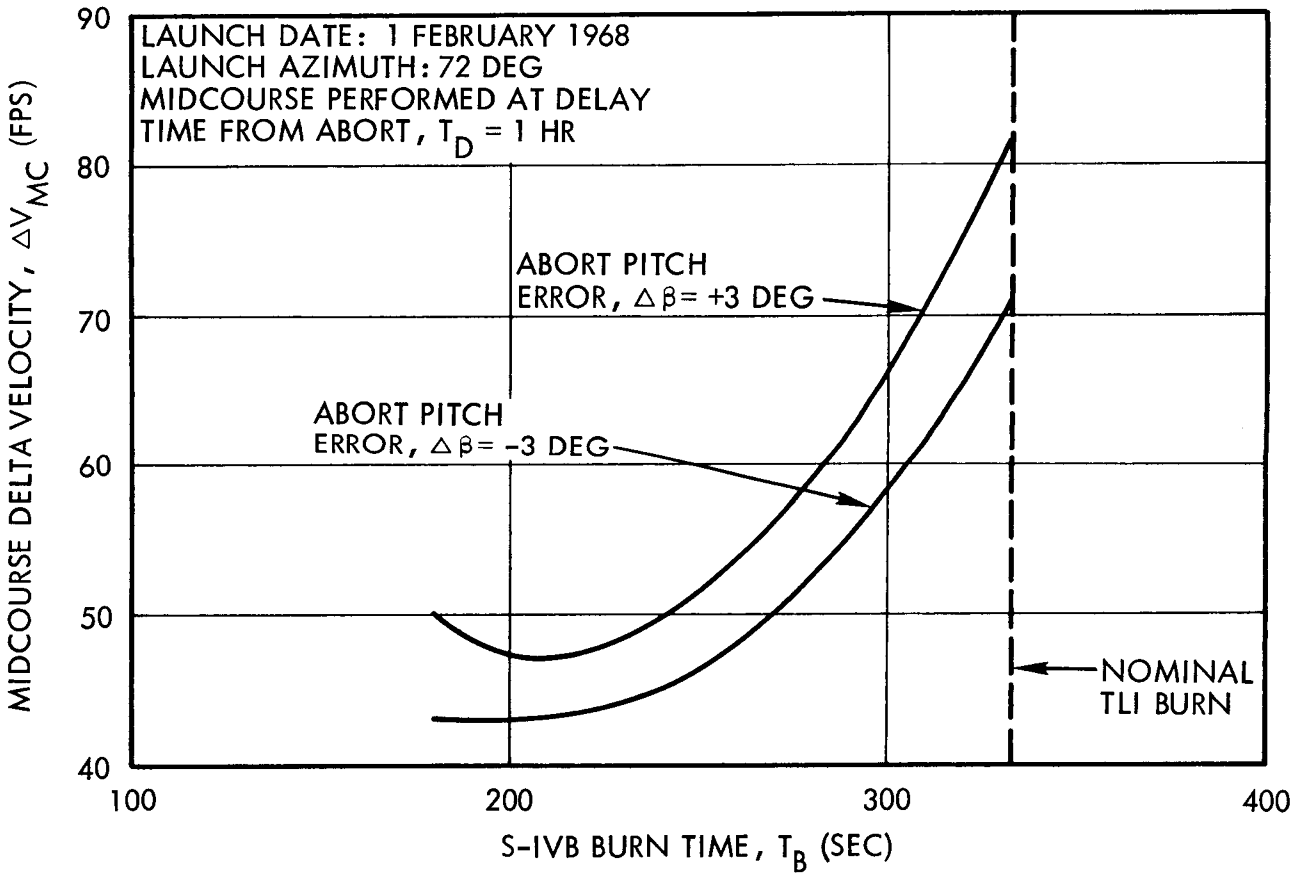

Figure A-3. Midcourse Delta Velocity as a Function of S-IVB Burn Time for Maneuvers Performed at T_D = 1 Hour

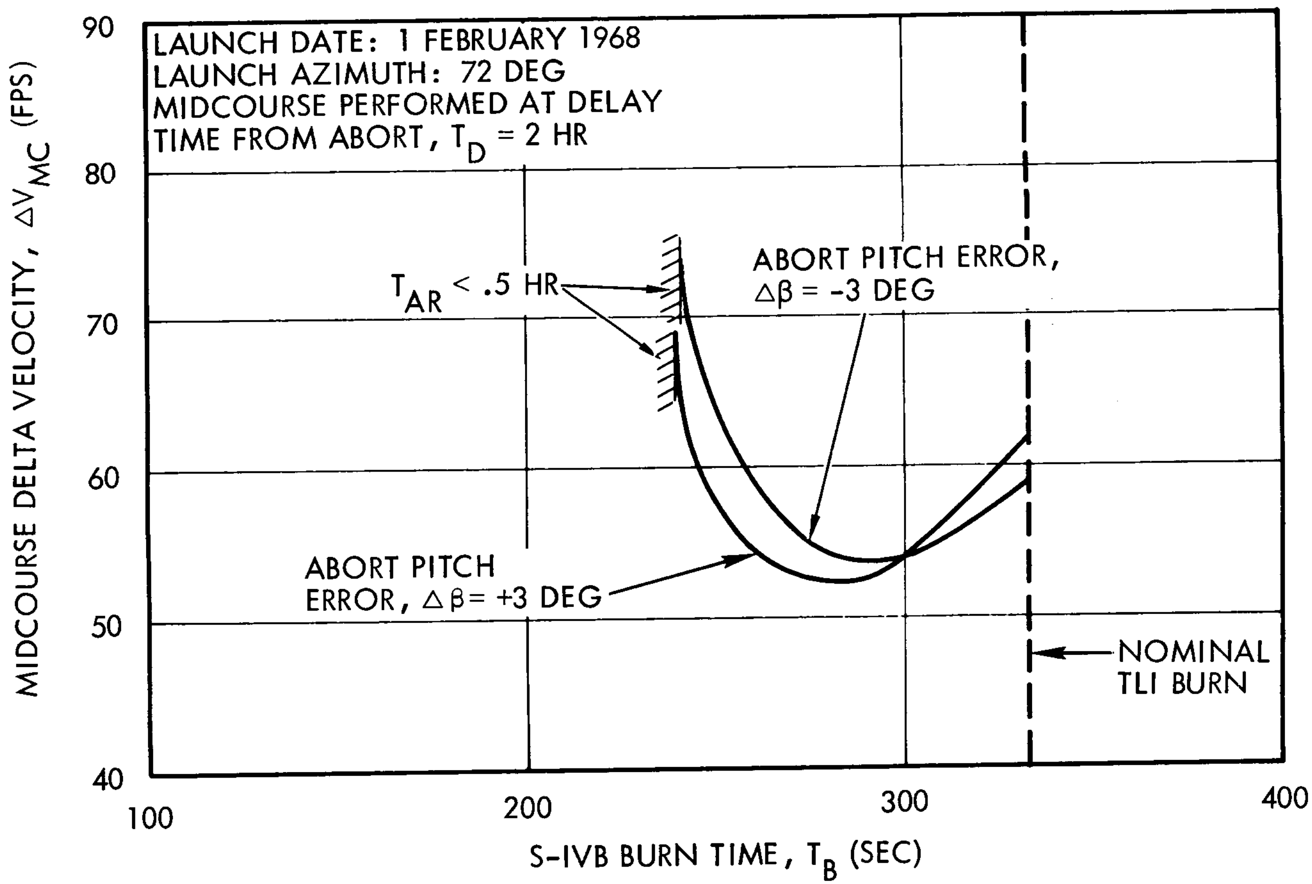

Figure A-4. Midcourse Delta Velocity as a Function of S-IVB Burn Time for Maneuvers Performed at T_D = 2 Hours

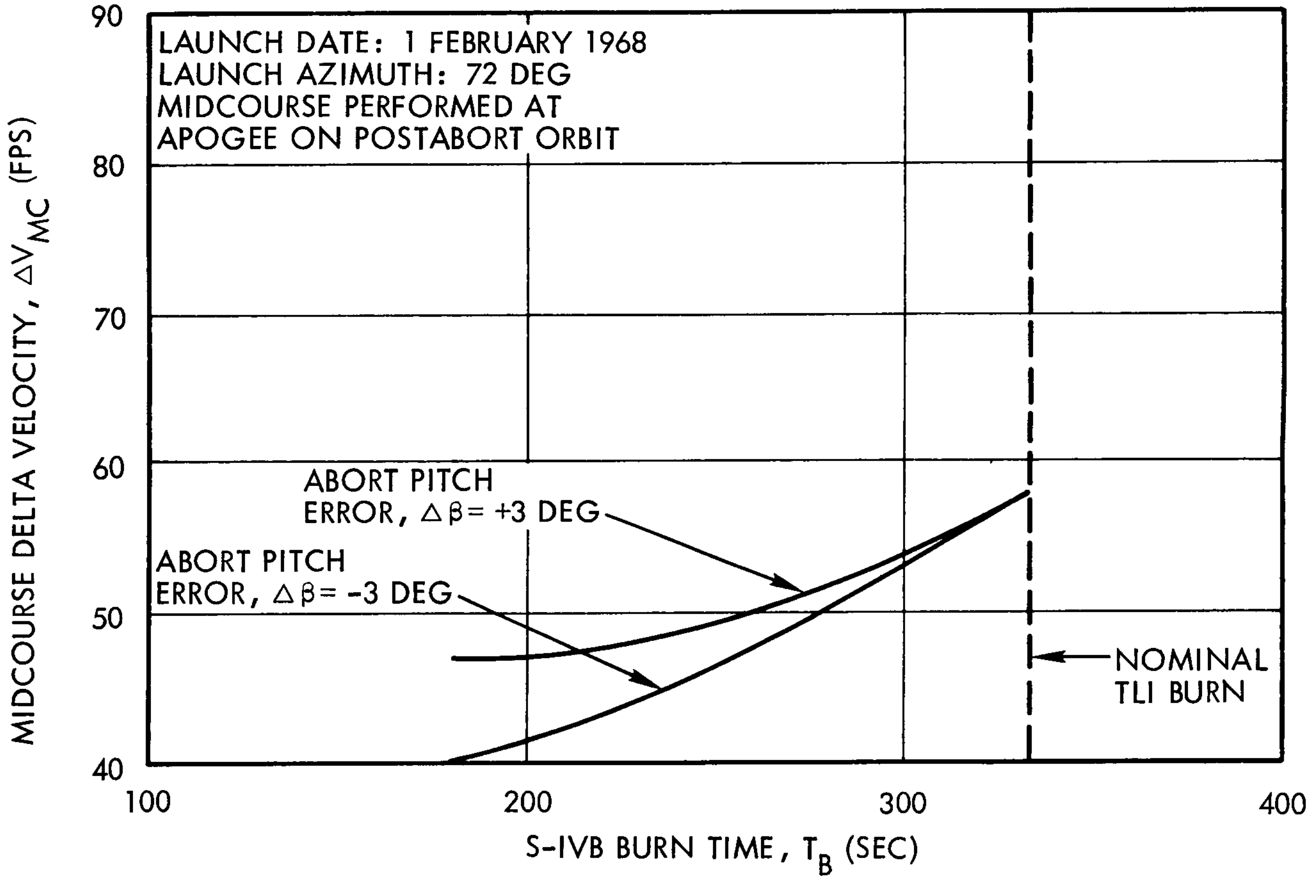

Figure A-5. Midcourse Delta Velocity as a Function of S-IVB Burn Time for Maneuvers Performed at Postabort Apogee

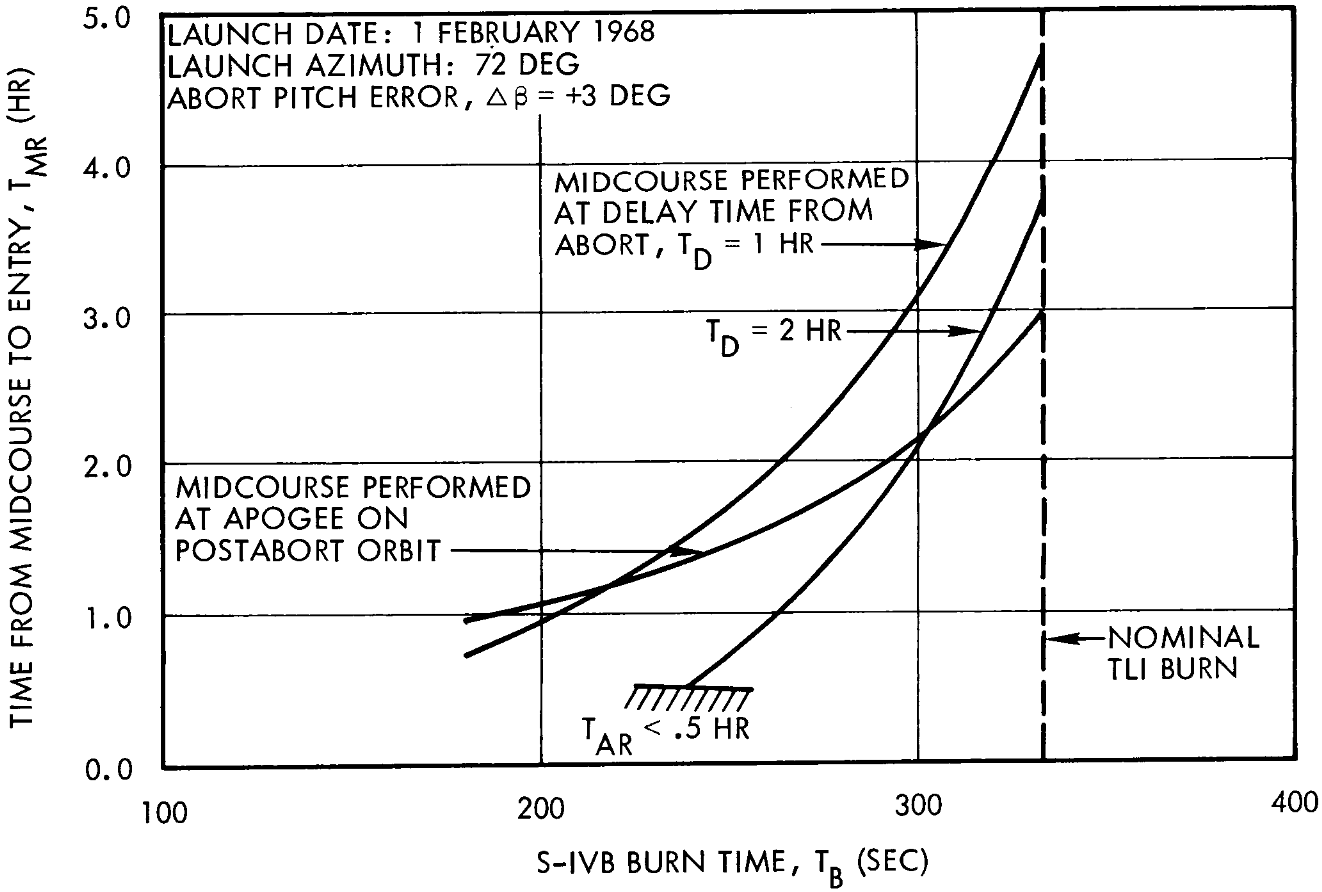

Figure A-6. Time from Midcourse to Entry as a Function of S-IVB Burn Time ($\Delta\beta$ = +3 deg)

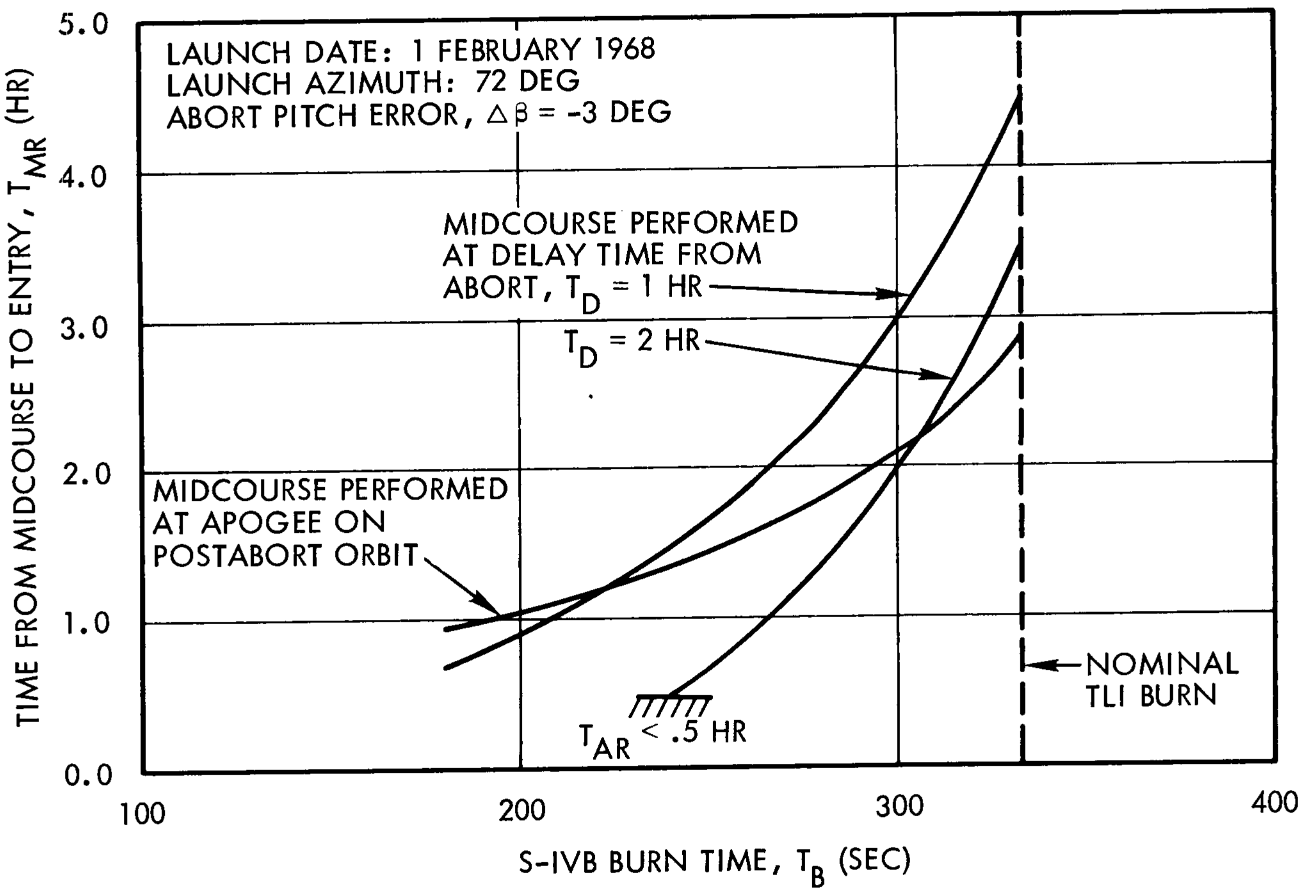

Figure A-7. Time from Midcourse to Entry as a Function of S-IVB Burn Time ($\Delta\beta$ = -3 deg)

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